Popular Astronomy.

Vol. XVII, No. 4. APRIL 1909. Whole No. 164

GEORGE WASHINGTON HOUGH.

GEORGE J. HOUGH.

FOR POPULAR ASTRONOMY.

In the passing away on the first of January of Professor George Washington Hough, director of the Dearborn Observatory at Evanston, Ill., the world of science lost one of its most useful members.

He was especially noted for his systematic study of the planet Jupiter, which he began in 1879 and continued for thirty years up to the time of his death; he was also famous as the discoverer of more double stars than any astronomer of his time, being credited with the discovery and measurement of more than 600 pairs, most of them difficult and beyond the reach of any but the most powerful telescopes. This brilliant work, and the marvelous scientific instruments due to his inventive genius, gave him a reputation as astronomer second to none in the world.

Born at Tribes Hill, N. Y. in 1836, he received his early education at Waterloo and Seneca Falls, manifesting great mathematical ability; and in 1856 graduated with honors from Union College, with the degree of A. B.; after teaching school for a year or two, he spent one year at Harvard University, where he took advanced work in mathematics and engineering, receiving his A. M. degree in 1859. The same year he became assistant astronomer at the Cincinnati Observatory under Professor O. M. Mitchell; when Professor Mitchell went to the Dudley Observatory the following year, he accompanied him as his assistant, and in 1862 became director, on the death of Professor Mitchell.

During the fourteen years that he spent at the Dudley Observatory, he accomplished a great amount of important work; his time seems to have been equally divided between astronomical and meteorological work. His systematic observations were of zone stars, nautical almanac stars and small planets; he invented a machine for mapping and cataloguing stars, which greatly simplified the preparation of star charts. In 1869 he

headed an expedition of astronomers sent to Mattoon, Ill., to observe the total eclipse of the Sun.

But it was in meteorology that he achieved the most brilliant results at this period. He invented a recording and printing barometer, the first and in fact the only successful instrument of this kind, and too well-known to need description here. He was awarded a gold medal for this machine at the Centennial Exhibition in 1876; and years later received a medal and diploma for the same at the World's Fair in Chicago.

About the same time he invented a second machine, called a meteorograph, which records every hour the changes of the barometer, and the wet and dry bulb thermometers; it is of simpler construction than the first named machine, but the principle involved is the same, namely, recording changes in the level of the mercury, by a float making electrical connection with the moving parts of the instrument. After these instruments were perfected, the U. S. Government had a number of them made for their own use; and one of the recording and printing barometers was made for a German observatory.

Another invention was the anemometer, for recording the velocity and direction of the wind; and after making thousands of observations with these machines, he drew some valuable conclusions showing the close relation between the direction of the wind and the atmospheric pressure.

He also made important investigations on the Daniel or Gravity battery, and was the first to suggest that lead could replace copper as the negative plate in the battery, besides making other important discoveries regarding the proper working of the battery. His investigations on the velocity of the electric current were also of importance.

He became an active member of the Albany Institute, and it was at the meetings of this society, that many of his discoveries and inventions were first given to the world. He was also active in the work of the American Association for the Advancement of Science, and at one time served as vice-president. For years he delivered a course of lectures on astronomy at the Albany Female Academy; and about this time was elected a member of the German Astronomical Society.

From 1879 to 1887 he was director of the Dearborn Observatory at Chicago, and did such valuable work there, that the observatory received a prominence it had not before enjoyed. It is hard to say where his most important work was done, as a man of his caliber cannot help being great whenever or where-

ever he labors; as we shall see, he made inventions and discoveries of equal merit in each of the localities where his life work was carried on.

During the first years in Chicago, he was associated with Prof. Burnham of double-star fame, and it was at that time that he became an enthusiastic searcher for undiscovered double stars. His important work on Jupiter began here, and we have a large amount of valuable information on this subject in the annual reports of the Chicago Astronomical Society. Of course he became interested in the Chicago Academy of Sciences, and along with his professional duties still found time to deliver many lectures before that institution.

It was in the early eighties that he brought to perfection his printing chronograph, an invaluable aid to the astronomer in his transit-work, and which is bound in a few years to be quite generally adopted by observatories. His observing seat for the equatorial, invented about this time, has also come into general use.

When it is remembered that Professor Hough made all his instruments with his own hands, and that the mechanical workmanship on them is extremely accurate, we can appreciate the mechanical ability of this man: indeed, he was an expert mechanic, not only in work, but in his thorough knowledge of the principles of mechanics; this trait he inherited from his father in whom it was also inborn.

When the Dearborn Observatory was moved to Evanston in 1887, Prof. Hough came with it as director, and also became professor of astronomy in Northwestern University; here he spent twenty-one years in the active and successful pursuit of his profession, during which time he completed his famous work on Jupiter and double stars.

The arrangement of the new observatory at Evanston was largely planned by him, and will always be a monument to his memory; here are found his scientific instruments, and the great dome which he himself invented in 1888, and which is superior to anything else of the kind.

He made other inventions here, namely, an electrical control for the equatorial, a dynamometer, and most important of all, a new form of storage-battery having great durability and which is manufactured and sold at half the price of the ordinary storage-battery.

For many years he took great interest in photography, and was once president of the Chicago Photographic Society; he also

invented an absolute sensitometer for testing photographic plates, and a new form of dry-plate holder; and a week or two before he died, he completed a new plate-attachment to be used with a folding kodak camera.

In scientific circles his influence was wide-spread; at the World's Congress in Chicago in 1893, he served as president of the section on mathematics and astronomy, one of the most noted gatherings of scientists and astronomers from all over the world, ever held in this country.

In 1891 he received from Union College the degree of Doctor of Laws; and the same year was elected to membership in the British Astronomical Association. But he received his greatest honor in 1903, when he was elected an associate member of the Royal Astronomical Society of England.

Other societies to which he belonged were,—The American Philosophical Society, The Astronomical and Astrophysical Society, The Astronomical Society of the Pacific, The American Institute of Civics, The Trinity Historical Society of Texas, and The Society of Sigma Xi, besides various social organizations.

He was in character a most lovable companion, quiet and unassuming, but full of interest for all that pertained to his friends, to the community, or to the institution with which he was connected; and he was loved and respected by all who knew him. As a friend has expressed it, he was "a quiet gentle scholar."

His knowledge and learning were varied and wide in their scope, and it was a rare privilege to associate with him.

He is survived by a widow, two sons, and two grandsons.

Evanston, Ill.,
March 3, 1909.

A SIMPLE METHOD DEVISED BY F. C. PENROSE FOR FINDING THE ORBIT OF A HEAVENLY BODY BY A GRAPHICAL PROCESS. III

ERIC DOOLITTLE.

For Popular Astronomy.

12. To find the True Orbit.—Up to this point the lines which we have drawn have all represented the projections of the corresponding lines in space upon the fundamental plane. We now imagine the plane of our drawing to be turned about the line $S\Omega$, Figure 10, as an axis, until it lies in the orbit plane, and

draw in this plane the orbit in its true size. Since BM and $B'M$ are both perpendicular to $S\Omega$, (which lies in both planes), and since $B'M = BM \sec i$, to obtain the position of the point B' it is only necessary to measure MB and then to extend this line to B', making $MB' = MB \sec i$.

It is usually convenient to make the drawing of the true orbit on a somewhat smaller scale than that of the projected orbit. Thus in figure 11, $a'e'$ is the true and AE the projected orbit, the scale of the former being one third that of the latter. The points a', b', etc. were found by measuring $Sn_1 = \frac{1}{3} \times SN_1$, $Sn_2 = \frac{1}{3} \times SN_2$, etc., and erecting at these points the perpendiculars $n_1a' = \frac{1}{3} \times N_1A \sec i$, $n_2b' = \frac{1}{3} \times N_2B \sec i$, etc.

Having found the points of the true orbit in this way, the curve is drawn through them as explained in (2), (3), and (4); the angle of perihelion, ΩSP, and the perihelion distance are measured from the figure, and, finally, the time of perihelion passage is determined as explained in (6*a*).

13. To predict the position of the body in the sky at any desired time.—This can readily be done by applying the principles which have already been developed. Thus, in figure 11, if it were desired to predict the position of the comet at the time t_5, we would first locate its position, e', in the true orbit by comparing the sector $d'Se'$ with the other sectors as explained in (6*b*). We would then draw $e'n_5$ perpendicular to $S\Omega$, lay off $SN_5 = 3 \times Sn_5$ and finally measure N_5E perpendicular to $S\Omega$ and equal to $3 \times n_5 e' \cos i$. The point E would then be the projection of the desired position.

We would next take from the ephemeris the longitude of the Earth and its distance from the Sun at the given time and with these quantities locate the position of the Earth at E_5. The straight line E_5E would then be the longitude line at the date desired, and the angle which it forms with the direction, SV, to the vernal equinox would be the longitude of the body. This would be measured from the figure.

To find the latitude, we measure the distances E_5E and E_5N_5 and then observe that since the height of the body above the fundamental plane is equal to $E_5N_5 \tan i$ and also to $E_5E \tan \beta$, we will have

$$E_5E \tan\beta = E_5N_5 \tan i,$$

or,

$$\tan \beta = \frac{E_5N_5}{E_5E} \tan i.$$

Having thus found the longitude and latitude of the body in

the sky we obtain from these the right ascension and declination by a computation which is explained later.

14.—We will now make the preceding theory clear by applying it to the determination of several orbits. With the first of these we will fully describe each successive step in detail, but the others will be treated more briefly, only those points which are unusual or liable to give difficulty being very fully explained.

For making these drawings the reader should provide himself with a sheet of drawing paper, (at least as large as 18×24 inches), two draughtman's triangles, and a straight edge, or ruler, at least 24 inches long. If he wishes the result of his work to be really accurate, he should employ two of the hardest, (6*H*), lead pencils, sharpened on fine emery paper, one to a chisel point, for drawing lines, and the other to a round point. When he has located a point on his drawing by measurement or otherwise he should use a fine needle for marking its position. Finally, he requires a pair of dividers and a so-called engineer's scale, on which the inches are divided into tenths.

The most convenient scale for the drawing is usually that on which the mean distance from the Earth to the Sun is represented by ten inches. The smallest division of the engineer's scale then represents 1—100th of the astronomical unit, and by estimation we can carry our work with some accuracy to thousandths. A copy of this scale should be made on a strip of the flexible drawing paper for measuring the lengths of curved lines.

Determination of the Orbit of Comet 1908 *c*, (Morehouse).

In order to obtain an accurate orbit of this interesting comet, we select a series of five observations extending over nearly three months. These will be found published in the *Astronomische Nachrichten*, Nos. 4275, 4283, 4290, and 4297 as follows:

No.	Local Mean Time	Apparent α	Apparent δ	Red. to Ap. Pl.	
				In α	In δ
	h m s	h m s	° ′ ″	s	″
1	*Sept. 12, 7 38 40.5	2 30 57.88	+72 27 36.0	+4.72	− 4.9
2	**Sept. 21, 8 2 32	0 25 31.82	76 25 35.6	6.55	+ 7.0
3	**Oct. 9, 9 14 28	19 54 47.49	60 26 1.5	0.86	23.4
4	†Oct. 23, 9 13 51	19 7 59.60	+36 13 58.8	0.54	18.8
5	††Dec. 8, 5 39 5	18 50 13.00	−11 3 0.0	+0.69	+ 2.7

*Rome. **Algiers. †Heidelberg. ††Bordeaux.

The above right ascensions and declinations are measured from the actual positions of the equator and vernal equinox on the several evenings of observation. But since, from various causes, the positions of the equinox and equator are always changing, it is customary to employ throughout all orbit work the so-called *Mean Position* which they occupied at the beginning of the year. The last two columns of the table contain the quantities which must be subtracted from the measured right ascensions and declinations, repectively, to obtain the values which these two quantities would have had if they could have been measured from the fixed, mean equinox and equator. These corrections are so small that they are almost inappreciable in graphical work, but as it is very easy to apply them we will do so.

The first step of our work is to change the local times recorded in the first column to Greenwich Mean Times and to decimals of a day. For the first observation, we find from the American Ephemeris for 1908, page 522, longitude of Rome $= 0^h\ 49^m\ 56^s$ east of Greenwich; hence, subtracting this quantity, we find the Greenwich Mean Time of the first measure to be Sept. 12, $6^h\ 48^m\ 45^s$ = Sept. 12.283 when reduced to decimals of a day. In this way the first two columns of the table below are obtained.

We next subtract the numbers of columns 5 and 6 from those of 2 and 3 respectively, and change the resulting right ascensions to degrees, minutes, and seconds. Thus from the above published measures we obtain the following table:

	Greenwich Mean Time					Mean α			Mean δ		
		h	m	s		°	′	″	°	′	″
1	Sept. 12,	6	48	45	Sept. 12.283	37	43	17	+72	27	41
2	21,	7	50	23	21.295	6	21	19	76	25	29
3	Oct. 9,	9	2	19	Oct. 9.377	298	41	39	60	25	38
4	23,	8	39	3	23.360	286	59	46	+36	13	40
5	Dec. 8,	5	41	11	Dec. 8.237	282	33	5	−11	3	3

We must now take from the ephemeris the longitude of the Earth and its distance from the Sun at each of the above dates. From page 148 we find, Longitude of Sun at noon on Sept. 12 $= 169°\ 17'\ 58''.1$, and the increase of longitude in one hour $= 146''.00$. As our first given time is $6^h\ 48^m\ 45^s$, $= 6.813^h$, past noon, the increase of the Sun's longitude during this interval will be, $146''.00 \times 6.813 = 16'\ 35''$, and the resulting longitude of the Sun at this time $= 169°\ 17'\ 58'' + 16'\ 35'' = 169°\ 34'\ 33''$.

The longitude of the Earth as seen from the Sun is always just 180° larger than that of the Sun as seen from the Earth, hence we have finally for the first longitude of the Earth, 180° + 169° 34′ 33″ = 349° 34′ 33″.

Similarly we have, log Distance = 0.0026024 − 47.5 × 6.813 = 0.0025700, of which the first four decimals are all that are required for graphical work. The number corresponding to this logarithm is 1.006, which is therefore the distance from the Earth to the Sun at the time of the first observation.

In this way we find the following values :

	L	R
1.	349° 34′ 33″	1.006
2.	358 24 12	1.004
3.	16 9 37	0.998
4.	30 2 3	0.994
5.	76 14 56	0.985

The only step which remains before we begin our drawing is to obtain the latitudes and longitudes of the comet which correspond to the above right ascensions and declinations. This is the longest computation connected with the graphical method and involves some knowledge of spherical trigonometry. It will be found explained in detail in many astronomies and in some trigonometries.* The most convenient method to employ is first to determine n and N from the equations,

$$n \sin N = \sin \delta$$
$$n \cos N = \cos \alpha \cos \delta,$$

and then to find λ and β from the equations,

$$\sin \lambda \cos \beta = n \cos (N - \epsilon)$$
$$\cos \lambda \cos \beta = \cos \alpha \cos \delta,$$

in which ϵ is the obliquity of the ecliptic. From page 286 of the ephemeris we find, $\epsilon = 23° 27′ 4″$.

The complete computation for the first measure is as follows :

log sin α	9.78663 p	cos $(N-\epsilon)$	9.75196 p
cos δ	9.47907 p	log n	9.98730 p
cos α	9.89817 p	sin λ cos β	9.73926 p
sin δ	9.97933 p	sin λ	9.96245 p
sin N	9.99203 p	cos λ cos β	9.37724 p
n cos N	9.26570 p	cos λ	9.60043 p
cos N	9.27840 p	tan λ	0.36202 p
tan N	0.71363 p	cos β	9.77681 p
N	79° 3′ 23″	λ	66° 30′ 56″
ϵ	23 27 4	β	53 15 46
$N-\epsilon$	55 36 19		

* See, for example, *Wentworth*, page 180, or *Bowser*, page 345.

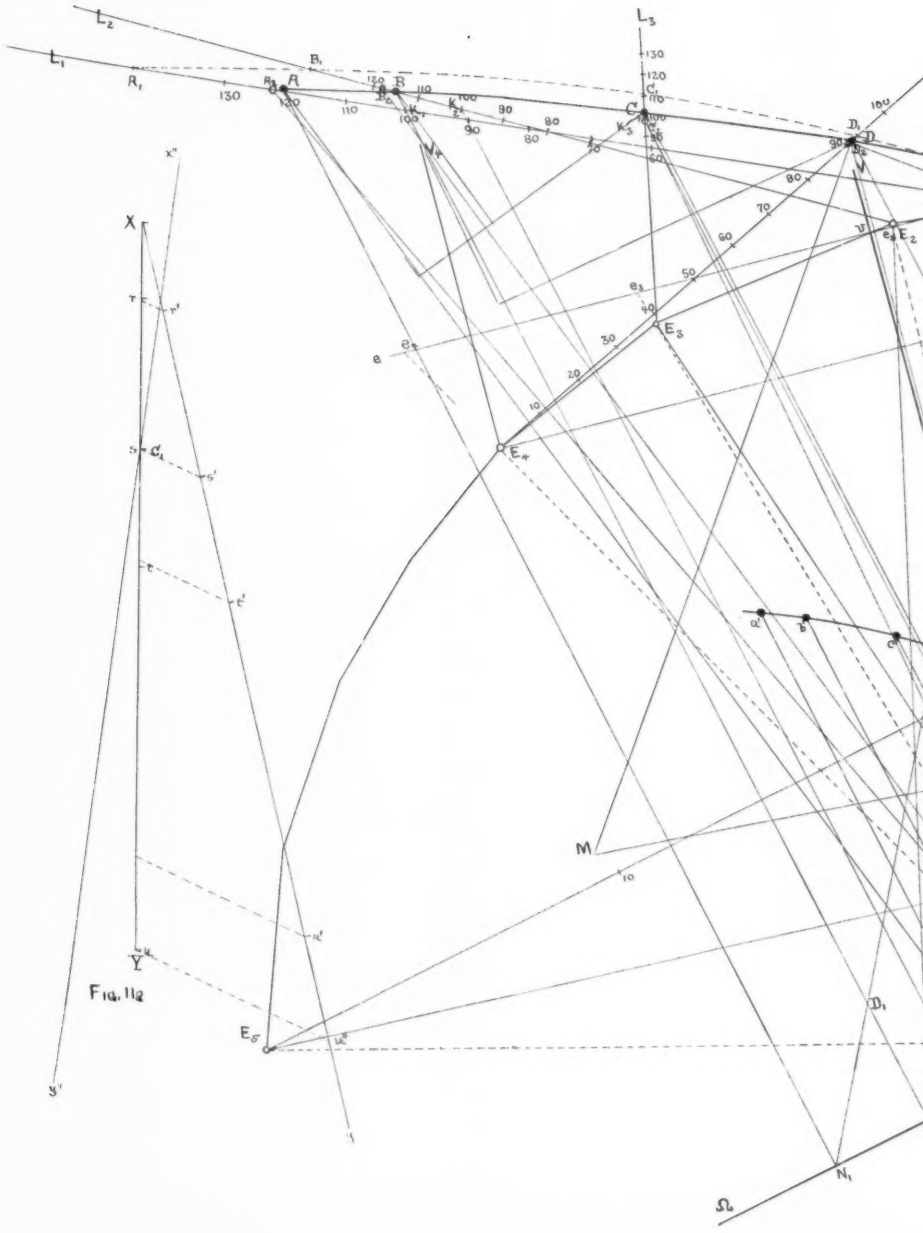
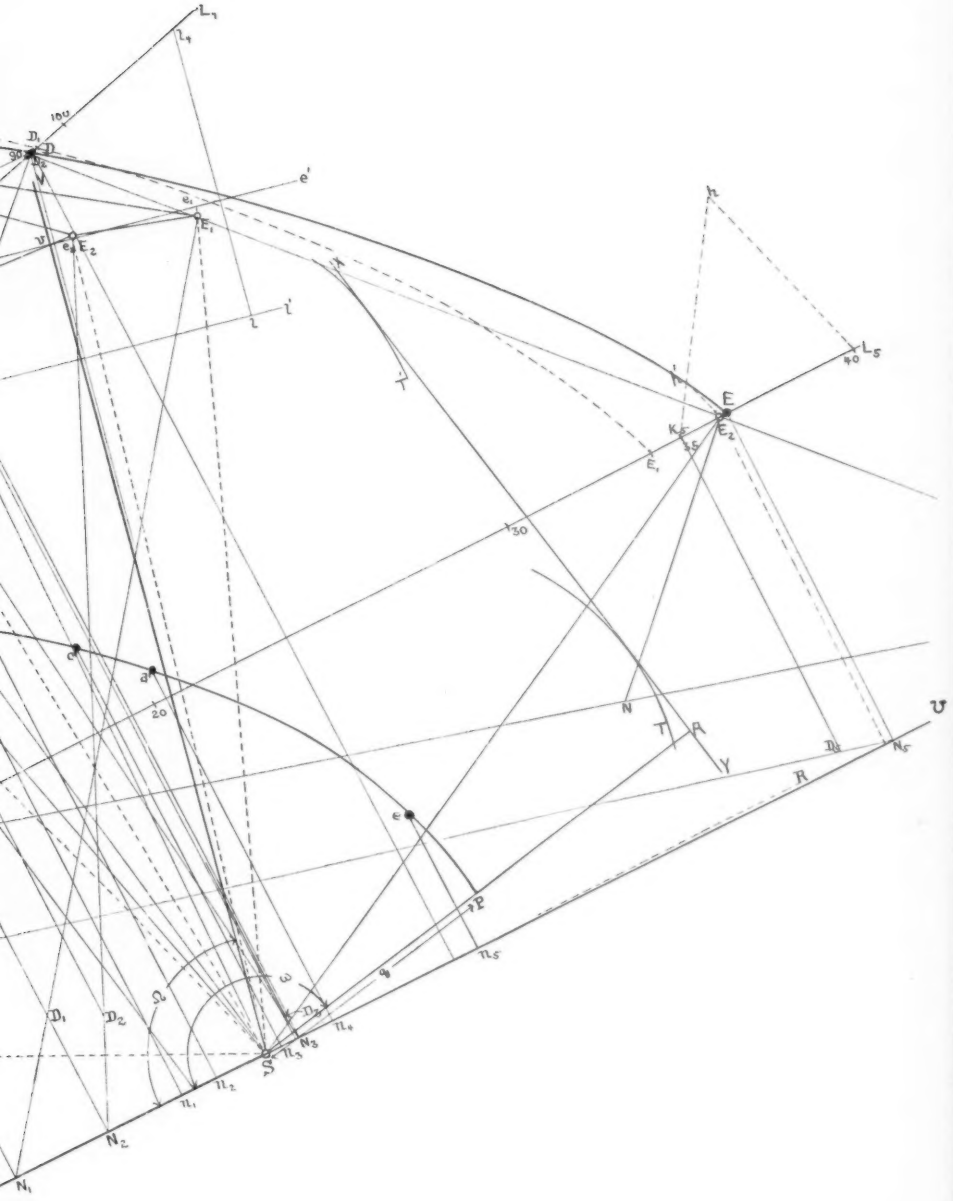


Fig. 112


L1
L4
10
D1
90
D
e'
e1
E1
e
E2
l
l'
T
h
L5
40
E
K
45
E2
E1
30
c
d
20
N
T
R
Y
D2
N5
R
υ
e
P
π5
ω
D3
π4
N3
S
π3
D1
D2
Ω
π2
π1
N2
N1

When the computation is made for each of the five dates we obtain the following results :

	λ			β		
1.	66°	30′	56″	+53°	15′	46″
2.	60	24	10	61	48	55
3.	347	50	46	75	58	20
4.	296	31	9	58	7	21
5.	282	35	14	+11	50	40

We begin our drawing by choosing a point S, figure 11, to represent the Sun and drawing a line SV to indicate the direction of the vernal equinox. We then construct the various positions of the Earth by drawing the angles $VSE_1 = L_1$, $VSE_2 = L_2$, etc., and measuring $SE_1 = R_1$, $SE_2 = R_2$. etc.

Such angles should always be drawn by employing their tangents. Thus we lay off $Sv = 100$ units of our scale and draw ee' perpendicular to Sv at v. We find from a table of natural tangents, tan L_1 = tan 349° 34′ 33″ = —0.1842, so that we lay off $ve_1 = 18.42$, join S with e_1, and along this line lay off $SE_1 = R_1 = 100.6$; E_1 will then be the first position of the Earth. When an angle exceeds 45° it is located in a similar manner from its co-tangent.

When the various positions of the Earth have been found in this way, we draw the longitude lines, E_1L_1, E_2L_2, etc., as explained in (8). Thus, for example, at E_4 we draw E_4V_4 parallel to SV, and since $\lambda_4 = 296°\ 31'\ 9''$, we draw E_4l' perpendicular to E_4V_4, lay off $E_4l = 100$ units on any scale, and perpendicular to this line draw $ll_4 = 49.90$ units of this scale = tan 26° 31′ 9″; the line E_4L_4 is then the desired longitude line.

We next graduate the longitude lines as explained in (10). The co-tangents of the several latitudes are as follows :

	Cot β
1.	0.7419
2.	0.5354
3.	0.2497
4.	0.6215
5.	4.768

The distances from E_1, E_2, etc. to the graduations marked 10 are hence, respectively, 7.42, 5.35, 2.50, 6.22, and 47.68; the distances to the 20 graduations are twice these, to the 30 points three times these, and so on. Hence, for example, with E_4L_4 we mark the points 10, 20, 30, etc., at the constant distance apart of 6.22 units, and similarly with the other lines.

All of the drawing so far made may now be drawn in ink if desired, as these lines will not be changed in the course of the successive approximations to the orbit.

We are now ready to find the first trial orbit. The time intervals are as follows :

$$t_2 - t_1 = 9.012 \text{ days.}$$
$$t_3 - t_2 = 18.082$$
$$t_4 - t_3 = 13.983$$
$$t_5 - t_4 = 45.877$$

It is at once evident that since B_1C_1 must be about twice A_1B_1, the orbit must cut the first two longitude lines very obliquely, and since C_1D_1 is to be 7-9ths of B_1C_1 the curve cannot lie further from S than shown in figure 11. A very slight outward displacement of B_1C_1 will be found to rapidly destroy the latter ratio, while, on the other hand, B_1 cannot be drawn much nearer to S without unduly shortening A_1B_1 or making a decided break in the curve at this point.

A convenient way to compare these ratios is to draw two intersecting lines XY and Xy, figure 11*a*, making the distances $Xr = 9.01$, $rs = 18.08$, $st = 13.98$ and $tu = 45.88$ on any scale. By direct measurement we find, $A_1B_1 = 2.14$, $B_1C_1 = 4.02$, $C_1D_1 = 2.60$ and $D_1E_1 = 8.18$. We hence lay off on any scale $Xr' = 2.14$, $r's' = 4.02$, $s't' = 2.60$, and $t'u' = 8.18$, join s and s' and draw parallel to this the lines indicated from the points r', t' and u'. Were the ratios of the arcs correct, these lines would meet XY in r, t, and u. But as drawn it is evident that A_1B_1 is too long compared with B_1C_1 and that the latter is of nearly the right length compared with C_1D_1. Finally, the arc D_1E_1 is very much too short. (When the ratios of the two middle arcs are nearly correct, as in this case, it is generally best to draw the second line in the position $x''y''$ and to lay off the distances both ways from $s = C_1$). These discrepancies can be overcome by bringing the arc A_1D_1 slightly nearer to S and lessening the curvature of D_1E_1 so that the distance E_5E_1 is increased.

When this has been done we join S with A_1, B_1, etc., and measure the sectorial areas, when we at once find that the first areas are much too large compared with the last ones. This is because the altitudes of the first sectors are so much greater than those of the last. As the process was very fully explained in (6), and to avoid unduly crowding the figure, the lines drawn in measuring these areas have been erased from figure 11. The result of each trial was to move the points A_1, B_1, and C_1 nearer to S, and the point E_1 further away; the third trial established the positions A_2, B_2, C_2, etc., for which the law of areas seemed to be satisfied. When numbers expressing the areas have been found, the ratios can be compared by the use of figure 11*a* as before described.

We next find the latitude numbers of these points and the position of $S\Omega$ as explained in (10). Thus, with the last position, L_5h was drawn five units long and the length of E_2h' was found to be 1.20 units; hence the latitude number of E_2 is 36.20. Similarly, that of D_2 was found to be 90.08. To find the line of nodes, the perpendiculars $E_2N = 36.20$ and $D_2M = 90.08$ were drawn, MN and D_2E_2 were produced, and their point of intersection was joined with S. The line SR was thus obtained, which is the position of the line of nodes from these two points. A similar construction was found from A_2C_2 and B_2D_2, and the line $S\Omega$ was then drawn in an average or mean position, the greatest weight being given to the position SR because the corresponding arc is the longest and because E_2 is nearer the ecliptic than the other points. By measurement we now find, $\cot VS\Omega = 0.217$; hence $\Omega = 102° 20'$.

We next find i from each point by the formula,

$$\tan i = \frac{\text{Latitude number}}{\text{Distance from } S\Omega}.$$

The results are as follows:

	Latitude Number	Dist. from $S\Omega$	i
1.	121.90	145 2	139° 59′
2.	118.15	139.8	139 48
3.	97.60	121.1	141 8
4.	90.08	108.5	140 16
5.	36.20	43.8	140 26

Forming the mean of the five values of i we obtain, $i = 140° 19'$.

We must now adjust the points to these values of Ω and i as explained in (11). On each of the first four longitude lines we let fall the perpendiculars to $S\Omega$ from the points whose latitude number is 100; on these perpendiculars we measure off K_1D_1, K_2D_2, etc. equal to $K_1E_1 \tan \beta_1 \cot i$, $K_2E_2 \tan \beta_2 \cot i$, etc. But since $K_1E_1 \tan \beta_1 =$ latitude number of $K_1 = 100$, and similarly with the other points, we have,

$$K_1D_1 = K_2D_2 = K_3D_3 \text{ etc.} = 100 \cot i = 100 \times 1.205 = 120.5.$$

Joining the points E_1D_1, E_2D_2, etc. and producing these lines until they meet $S\Omega$ in N_1, N_2, N_3, etc., and finally erecting the perpendiculars N_1A, N_2B, etc. at these points, we obtain the points A, B, C, etc. of the adjusted orbit. (This construction alters the position of D_2 so slightly that the lines for this point are omitted from the figure).

We now join the points A, B, C, etc. with S and measure the sectorial areas. We obtain:

$$A_1 + A_2 = 0.53 \quad (t_2 - t_1) + (t_3 - t_2) = 0.559$$
$$A_2 + A_3 = 1.26 \quad (t_3 - t_2) + (t_4 - t_3) = 1.293$$
$$A_3 + A_4 = 0.30 \quad (t_4 - t_3) + (t_5 - t_4) = 0.305$$

As this agreement is satisfactory, we may assume that *ABCDE* is the true position of our final projected orbit.

To draw the true orbit, we assume a scale one third as large as that used heretofore. We lay off $Sn_1 = \frac{1}{3} SN_1$, $Sn_2 = \frac{1}{3} SN_2$, etc., and perpendicular to $S\Omega$ at these points lay off the distances $n_1a' = \frac{1}{3} N_1A \sec i$, $n_2b' = \frac{1}{3} N_2B \sec i$, etc., thus obtaining the points a', b', c', etc. of our developed orbit. We find: $\sec i = 1.2994$,

	N_1A, etc.	n_1a', etc.
1.	14.47	6.27
2.	13.84	5.99
3.	12.28	5.32
4.	10.87	4.71
5.	4.38	1.90

To draw the true orbit through these points, we choose e' as a center and with a radius $e'S$ draw the arc T; also with a' as a center and a radius $a'S$ we draw the arc T'. The line XY tangent to these two arcs is the directrix, the line SA drawn from S perpendicular to the directrix is the axis, and the point P midway between S and A is the perihelion, as was all fully described in (2). We find by measurement that $\tan PSn_5 = 0.186$, whence $\omega = \Omega SP = 169° 28'$. We also find $SP = q = 0.965$.

It now only remains to find the time of perihelion passage, T. We have, Area $PSe' \div$ Area $a'Sb' = 1.238$; hence T = Dec. $8.237 + 1.238 \times 9.012$ days = Dec. 19.409. The mean as obtained from all the sectors is found to be Dec. 19.566.

Our entire series of elements are therefore as follows. For comparison with them we write what are probably the best series so far computed and also the first, preliminary elements obtained from observations made on the first three nights after discovery only. The accuracy of the graphical method in this case is due to the very long arc which was used in the construction.

ELEMENTS OF COMET 1908 *c*, (MOREHOUSE).

	Graphical Method	Best Elements*	Preliminary Elements**
T	1908 Dec. 19.566	Dec. 25.7754	1909 Jan. 5.70
ω	169° 28′	171° 39′ 44″.7	152° 4′
Ω	102 20	103 11 56 .7	90 21
i	140 19	140 11 7 .4	135 56
q	0.965	0.94465	1.168

The University of Pennsylvania.

* *A.N.* 4275. ** *A.N.* 4273.

NOTES ON AN ARGUMENT AGAINST AN INFINITE UNIVERSE.

OWEN ELY.

FOR POPULAR ASTRONOMY.

In the December number of POPULAR ASTRONOMY Mr. E. A. Fath has criticized my argument in proof of a finite universe,* asserting that Newton's Theorem of the spherical shell (Book I, XII, Prop. LXX, Principia) is in opposition to my conclusions and proves my reasoning fallacious. But the application of the Theorem leaves out of consideration the force which I believe is proof of my proposition—gravity (not gravitation).

Assuming a homogeneous sphere of matter extending *n* light years from the Earth as center, the Earth, as Mr. Fath has explained, would be attracted in every direction with forces of equal intensity and neither the Earth nor any part of it would be set in motion by those forces: and since *n* may be finite or infinite, nothing is proven. This apparently negatives my conclusion, but it omits the essential facts—the facts of gravitational cohesion and planetary revolution. To make this clear let us begin where such a discussion should begin, by examining the possible causes of the constant re-adjustment of position of the heavenly bodies—for, since there is motion which is not attributable entirely to inertia we know that the Theorem is not applicable, *i. e.*, that the attractive forces tending in opposite directions are unequal: nor can we avoid this conclusion, as I shall later emphasize, by imagining the Sun and planets as agencies apart or in some way distinct from the universe of stars: we must consider them as much a portion of that universe as are any other bodies in space. Considering the possible causes of motion, other than inertia, we see that the attractive forces, which we attribute to gravitation alone—for there is the highest probability that were any other sufficient force besides gravitation in operation, its existence would have been disclosed—could only be unequal in opposite directions under two circumstances, (1) that the Earth is not in the center of the universe, (2) that the universe is not homogeneous: for in either case the amount of matter in some directions from the Earth is greater than in the opposites of these directions.

When we applied the Theorem the significance of the "shell"

* Aug.-Sept. no. *Popular Astronomy*.

was perhaps misunderstood. According to Mr. Fath's explanation it might be regarded as representing the whole homogeneous universe. The Theorem states that "a corpuscle placed within these superficies will not be moved," which means simply that the corpuscle may be at the center or at any other point within the sphere. Accordingly it would be said that the Earth might be in any part of the homogeneous universe without being set in motion by gravitation. But comparing the Earth to the universe, is there any particle but that at the center which does not gain motion when free to move? The "spherical shell" must be defined as only that vacant space lying between the Earth and the "layer of stars." For it is perfectly clear that if we attempt to enlarge the extent of the sphere thus described, so as to include some stars, or even the Sun and planets, the "centripetal forces" at every point of the spherical surface will in some cases tend outward and in some inward; and if we include all the stars all the centripetal forces will be toward the inside, which is contrary to the hypothesis of the Theorem. By "superficies" then we mean the general boundary between the empty space about the Earth and the space beyond filled with stars. Nowhere in the empty space will the Earth be set in motion, but if it be placed in what I called star-filled space, not in the center of the universe, the amount of matter lying in different directions, hence the attractions, are unequal and motion ensues. This explanation is unnecessary to the argument but makes clear the validity of the first possibility.

One or both of those circumstances, I have said, constitute the only possible condition of the universe such that motion would ensue from the operation of gravitation. I have shown how motion would thus result from them, on the assumption of a finite universe; and astronomy seems to show that both conditions are existent. But now assume that the universe is infinite and see whether either of these circumstances would allow such result. The first is invalidated, for at whatever point in space the Earth be situated, that point may be taken as the center of the universe. The second also, it appears to me, is eliminated, and thus we are left with the plain statement that in an infinite universe gravitation could be no cause of motion. By this *reductio ad absurdam* it is evident that the universe is finite.

The elimination of the possibility that non-homogeneity might produce motion follows from these considerations: If the amount of matter continually decreases it must approach a

limit zero, so the extent is not infinite. If it continually increases in amount it must also approach a limit beyond which is homogeneity so that the effect is equivalent to that of an entirely homogeneous universe. Alternate increases and decreases, however fluctuating, are equivalent to homogeneity, since, having an infinite space in which to measure them out, star-layers can always be adjusted to be of equal extent, such that the sums of the alternate increases and decreases in each of them are equal: the only alternative of such possible arrangement would be continual increase or decrease in the sums. If the amount of matter varies differently in some directions than in others, as is the exact fact, the effect is still an infinite attraction in every direction, just as an infinity of one's is equal to an infinity of hundred's. It is evident that non-homogeneity in an infinite universe would be equivalent to homogeneity.

The point upon which I lay emphasis is, that the attractions of the Sun and planets, so immensely greater than those of the rest of the universe, are not because of that fact to be excluded from what may be called our "universal system" of forces tending to every point of the "superficies". To assume that they are to be excluded as extraneous factors would be nearly to destroy the whole basis of the argument, for the influences confined to the solar system are practically the only causes of the Earth's motion. Such an inadequate conception of the problem might produce the contention of somewhat this character: since the forces of universal attraction—finite or infinite—tending in every direction are balanced by equal contrary forces, the field is clear for the operation of gravity and solar attraction so as to produce motion in the case of the Earth. But the only logical method is simply to consider the Sun and planets as contained in a section or sphere of the universe which is non-homogeneous. The universe being finite, the non-homogeneity of this section may cause forces tending in some directions to be any finite multiple of forces tending in other directions; as is evidently the fact. But what if the universe were infinite? Any manner of distribution of matter is then equivalent to homogeneity. The attraction is infinite in every direction, and the attraction of the Sun could add nothing to the infinite force already tending in its direction, hence would be absolutely inconsequential—the Earth would no longer be held to its orbit.

But this reasoning does not reach the root of things. We should apply it not only to the Earth but to a gravitational particle itself. The universe being finite, the other particles

composing the Earth are a portion of the universe non-homogeneous with the remainder, hence it is possible that there be exerted in some directions forces millions of times greater than in the opposites of those directions : that is, we say, the apple falls to the ground. But were there already infinite forces tending every way the forces of gravity could neither add to nor detract from the infinite--the apple would be as Mahomet's tomb. In such a case the Earth's particles would cease to follow a circle about the axis, each would fly off at a tangent and soon be lost in the depths of space. The result of such a transmutation of the universe by the dissolution of all masses which would so tend to dissolve in space, would doubtless be a rapider rate of distribution of unavailable energy than at present, ending, I believe, in a universe perfectly homogeneous in regard to both matter and energy.

Another viewpoint of the whole argument : In the evolution of the present nature of things the Earth and all bodies were formed by a gradual massing of particles. In the beginning, then, there existed a universe of gravitational particles nearly if not perfectly homogeneous. Had the universe been infinite, Newton's Theorem would have applied to every particle, all the infinite forces acting on it being equal : hence no motion would have been impressed upon any particle and no conglomeration of particles would have taken place.

The only weakness of the "gravitational argument" is that it neglects a probable factor—the time-element. It certainly appears as though the argument that "an infinite universe would cause an infinite amount of light to reach the Earth," the objections to which astronomers have been trying to overcome for many years, is wholly invalidated by the introduction of the time-element : for the speed of light is finite, and light can only reach the Earth from an infinite distance in an infinity of time. It is evident that, since an infinity of time has not yet passed by, light can only reach the Earth from finite distances, and whether those finite distances mark the boundary of the universe or not we cannot assert. It seems scarcely possible that the speed of gravitation should be infinite; and accordingly the new argument is weakened in the same way that the old is invalidated : for motion in a non-homogeneous and infinite universe might then be possible. Likewise we cannot assume the invariable operation of gravitation according to Newton's Law, throughout all the universe.

However, if we catch any glimpse of the truth by the examina-

iton of such modes of reasoning, probability points toward a finite universe. If such a decision be more than prejudice, and mere assertion of opinion be not therein disguised in the language of logic, we would re-iterate the statement of A. M. Clerke*: "In actual fact, an infinite universe would be chaos, not a cosmos. Undisciplined by measure, the physical forces would run riot in it. It could have no structure, no parts, no intelligible plan. To our puny investigations it would present the blank aspect of an eternally insoluble enigma. . . . The stars and nebulae form together a stupendous system, framed on lines dimly significant of an origin and progressive relations. But a system cannot be infinite—not, at any rate, in a sense intelligible to the human intellect. . . . A numerical infinity is inconceivable—discrete quantity is by its nature finite. Both observation and rational inference indeed, while setting no bounds to the display of creative energy, enforce belief in a terminated siderial world."

Saint Paul, Minnesota.

† *Pop. Astro.*, Vol. IV, page 431.

AN ASTRONOMICAL THEORY OF THE MOLECULE AND AN ELECTRONIC THEORY OF MATTER.

Solar and Terrestrial Physics Viewed in the Light Thereof.

SEVERINUS J. CORRIGAN.

For Popular Astronomy.

Part IV. (Continued.)

The Terrestrial Atmosphere. Its Volume, Extent, Density, Pressure, Temperature and the Meteorological Effects caused therein by the Solar Electro-Magnetic Radiations.

Several other facts of observation will now be adduced to demonstrate the electrical origin of the tornado, one of these facts being that a hailstorm, which is always coincident with a thunderstorm, (although the latter phenomenon may and does often occur without the former) is always confined to a

narrow, and comparatively, short belt of country, very similar in dimensions to the path of a tornado which very frequently—if not always—is accompanied or followed, by a downfall of hailstones and by a copious precipitation of rain.

In fact, observations made by myself and by others, as well as theoretical considerations, seem to indicate quite clearly that a hailstorm is always and solely a result of a more, or less, pronounced vorticose motion in the lower atmosphere, although the action may be masked, not having developed sufficiently to cause visible manifestations below the general level of the clouds nearest the Earth's surface, or to assume the distinct, typical form of the tornado which is a comparatively rare phenomenon at any given place, in its fully developed aspect, but in its incipient form aforesaid it does occur more frequently than is recognized by the general public. In past years, in the season, and during the hours of the day, when atmospheric conditions were favorable for the generation of a tornado, I have, a number of times, observed decided indications of vorticose motion in the clouds passing over this city and in some cases even the development of a short funnel reaching toward the surface of the Earth, but never descending to the latter, or causing any noticeable atmospheric disturbance thereon, as in a case observed by myself and others in the summer of 1898, when a tornado-cloud passed northeastward over this city with a short funnel dependant therefrom, which dipped and rose a number of times, but never reached the surface by a considerable distance—at least while under my observation which continued until the phenomenon disappeared near the northeasterly horizon. At other times I have noted short-lived disturbances, covering only a few hundred feet, which were distinctly vorticose in nature, and sufficiently strong to level many trees, but which would not generally be regarded as tornadoes.

The mode of formation of hailstones in the case of the tornado becomes quite evident when it is considered that there is a spiral uplift of raindrops from the lower clouds into the higher and colder regions where the temperature is below the freezing-point of water, the drops of water in this case being converted into globules of ice which fall to the Earth, but if there be, as is often the case, several repetitions of this falling and uplifting process before the globule reaches the surface, it will be covered with alternate coatings of snow gathered in the upper regions, and of ice formed lower down, this type of hailstone being very common.

Warm, moist air from near the Earth's surface, drawn upward through the funnel of a tornado, expands in the colder upper regions, this expansion itself cooling the rising air by definite degrees according to well established laws of the thermodynamics of gases, the cooling below the point of saturation causing condensation of the aqueous vapor in the ascending mass of air, into the dense, black clouds characteristic of the tornado, as the air thus uplifted spreads out above, this cloud formation assumes the shape of an open umbrella, the dependant funnel representing the stem or handle thereof. But often in regions where the air is dry and hot—as in some of the desert portions of Africa, Arabia and India—phenomena of the same fundamental nature as the tornado, do occur without the formation of any clouds, as in the case of the peculiar, whirling dust-storms observed by travelers in the desert regions aforesaid. Furthermore, water-spouts at sea and "cloud-bursts" in mountainous regions where the tornado itself seldom, if ever, occurs, are also the results of vorticose motion attributable to the same cause as that which generates the tornado proper. The column of water drawn up in the funnel of a water-spout—by reason of the partial vacuum therein,—is very narrow compared with the funnel of a tornado, and this modification of the tornado cannot exist very long after the funnel dips to, or near, the surface of the sea and begins to draw up the water, because the latter serves as a conductor for the discharge of the electricity which is the prime generator of the vorticose motion that in the case of a waterspout is according to my theory the same as that of a true tornado until suction of the water upward into the vortex-tube begins, when loss of electricity to the Earth checks this vorticose motion; but if the electrical action in the upper part of the vortex be very great, there may be formed another funnel, or spout, or perhaps several such vortex-tubes two, or more, being often seen traveling in company over the surface of the sea.

The nature of the electrical action will now be considered. When two masses of cloud-laden air in which the moisture acts as an electrical condenser, are oppositely electrified and the tension, or the difference of electrical potential, between them becomes sufficiently great, a discharge, in the form of ordinary lightning, which is the result of the disruption and recombination of a long, and almost inconceivably thin, line of atmospheric molecules, will pass between them and electrical equilibrium will be either wholly, or partially, restored thereby, but

when the tension is comparatively low, there will be an accumulation of electrified matter, floating in the surrounding atmosphere, and insulated thereby, the motion of the atoms of the disrupted molecules, unable to recombine, being often so rapid as to render the affected matter incandescent, such matter, pressing outward equally in all directions, but being reacted upon by the pressure of the surrounding, unaffected atmosphere, it presents the well-known phenomenon called "ball-lightning."

Now, while a partial vacuum is formed by the expansion and subsequent contraction, or collapse, of the expanded, gaseous matter of the atmosphere, along the thin line of the lightning-flash, it endures for only an almost inappreciable time (the apparently sensible duration of a flash—probably the tenth part of a second—being due to what is known in optics as the "persistence of vision", whereby a very bright light so affects the retina and optic nerve in the eye of an observer, that an image remains impressed thereon, even after the original has disappeared by the aforesaid length of time—a principle upon which the operation of the so-called "moving-pictures" depends,) and does not suffice to cause the vacuum necessary for the inception of the vorticose motion of the air in the case of a tornado; but when the atoms of the disrupted molecules, or in other words, the atoms of the electrified gases, are unable to recombine for a sensible time and therefore remain, expanded and suspended in the form of an insulated ball—generally incandescent—do collapse suddenly, a very considerable vacuum must be formed in toward which the surrounding atmospheric gases at, or near, normal pressure, will be urged in a more, or less, circular path, or with a vortex-motion, the moving masses of air then obeying the laws of hydromechanics and thus forming a tornado. Therefore, according to my theory, a free play of lightning among the clouds is very unfavorable to the formation of the latter phenomenon, because electrical equilibrium is being almost instantaneously restored, each flash enduring for probably much less than the ten-thousandth part of a second; indeed, if as is most probable, the velocity is that of light, the duration of a flash, one mile in length, would be only $\frac{1}{186340}$ of a second although the impression upon the optic nerve would cause an apparent duration of as much as $\frac{1}{10}$ second. On the other hand, in the case of ball-lightning the phenomenon may have an actu-

al duration of several seconds and be directly conducive to a disturbance of atmospheric equilibrium, in the manner that I have described above, although the spherical mass of insulated, electrified air may not become incandescent.

My theoretical conclusions in this immediate connection, which are attested by my own observations of the phenomena, as well as by the published statements of other credible witnesses in divers cases, are the following: First, when atmospheric conditions in a storm are otherwise indicative of the possibility of a meteorological disturbance of this kind, the lightning is vivid and of a bluish tint, the discharges between the oppositely electrified cloud-masses being very frequent, the flashes long and the thunder sharp, prolonged and almost continuous, there is comparatively little probability of the formation of a tornado because electrical equilibrium is, in such case, almost instantaneously restored, after each disturbance thereof.

Secondy, if the discharges of electricity between the clouds are comparatively infrequent, occuring only fitfully, the consequent flashes of lightning being short and of a reddish hue (indicating according to my theory a much lower electromotive force than when they are vividly bluish) the thunder consisting of short, but loud and explosive, detonations like the sound of the discharge of large cannon, or of a bursting bomb, (such being the report following the discharge of ball-lightning, or the collapse of an expanded, highly electrified spherical mass of air, as described on a preceding page) the probability of the formation of a tornado is greatly enhanced; particularly when, as a third case, a very active thunderstorm the electrical discharges whereof are those described in the first, ceases with an abnormal suddenness instead of gradually dying out.

A fine and instructive example of the development of a tornado under the second set of meteorological conditions came under my direct observation, in the case of one that passed only a few miles from the center of this city, on July 13th, 1890, to which I referred in the last number of POPULAR ASTRONOMY, this particular tornado having been a typical one, of great violence, all meteorological conditions, especially as to the season and the hour of the day, having been extremely favorable to the generation and development of the phenomenon which was witnessed by many throughout a quite extended area of the surrounding country. The day, even in the morning when the sky was clear, was a hot one, the atmosphere in the earlier part of the afternoon becoming abnormally calm, and an oppressive sultri-

ness prevailed, even animals exhibiting signs of unwonted uneasiness. The sky became overcast with clouds and a storm appeared slowly gathering in the west, heralded by low, dull mutterings of thunder, but the flashes of lightning were few, infrequent, short and not sharply defined, their hue being a rather dull red indicative of a low voltage, or electromotive force, compared with that of the long, vivid flashes aforesaid; a little rain fell, but only spasmodically, in spatterings of very large drops, just after each lightning-flash, the total quantity for some time prior to the advent of the tornado being only a trace, as if precipitation were somehow abnormally impeded.

As I watched the western sky, in anticipation of meteorological disturbance, I noticed, at an altitude of about fifty degrees, a considerable commotion among a small collection of clouds, which were darting about in divers directions and exhibiting a decided tendency toward a vorticose movement. This center of disturbance then began to drift with increasing velocity toward the north, (instead of eastwardly as is the case with tornadoes in general) a peculiar circumstance that led me to look toward that point of the compass where I descried the densely black upper portion of a great tornado, evidently in full action, looming above a hill covered with trees and thick foliage that obstructed the view considerably. The tornado was then a little to the west of north, and moving with considerable rapidity in a general easterly direction which is practically the case with all these phenomena, the course in three-fourths, at least, of the hundreds observed, being to the northeast, and the incipient whirl that I had first observed almost directly west, was drawn northward by, and merged into the main vortex.

The altitude of the top of the tornado-cone where it sprang from the general level of the lower clouds and extended, in funnel-shape, toward the Earth's surface, was, according to measurements which I made with my sextant, nearly eight degrees above the horizon, and since the horizontal distance of the phenomenon from my point of observation at the time, was, as subsequently found, approximately six miles this distance multiplied by the tangent of the altitude (eight degrees), gives as the height of the inverted base of the funnel, and approximately that of the general level of the lower clouds, about 4,000 feet in this instance, and this is probably the height in the case of all well-developed tornadoes, while in that of others it may be greater, but, probably, not more than 6,000 feet, or a little above a mile. Of course, the height of the point at

which electrical action begins to cause the vacuum necessary for the development of the phenomenon, may be greater and above the lower general level of the clouds which obscure the action at its inception, so that a determination of the height of this point cannot be made by instrumental measurement, but it may be deduced from the general theory of the constitution of the atmospheric envelope, and the meteorological conditions prevailing therein. The sounds emitted from the vortex of this tornado, which was, as aforesaid, at a distance of about six miles from my point of observation, were audible to me, being like the hum of a multitude of rotating pieces of milling machinery, as the predominating sound, although heavy detonations were heard at intervals.

The angular width of this tornado in its upper portion where the diameter of the vortex-tube was greatest, was about twenty degrees, which correspond to a linear diameter of about 11,000 feet, or nearly two miles, at a distance.

The dimensions in this case were such as those that appertain to a tornado of the first class. The length of path over which considerable destruction of life and property was wrought, was not more than about ten miles, though the total course through the country which was then only sparsely settled, may have been longer; but had it passed over the city, or though a well-populated country district, the magnitude and violence of this tornado would have been marked; yet even at that time it attracted a great deal of attention from the inhabitants of this section. The time of occurrence—between 3 P. M. and 6 P. M.—was that most favorable for the development of such meteorological disturbances, which are quite infrequent during the morning hours and after 8 P. M.

In every respect, both as to atmospheric and other meteorological conditions at the the time of its occurrence, and its dimensions, motions, aspect and other concomitants, this tornado was clearly illustrative of the second set of conditions above set forth.

About two weeks afterward, on an afternoon of a day when there were few if any portents of such an occurrence, the air being cool, the clouds comparatively light and no ominous calm prevailing, I descried to the northward of this city, and moving over almost exactly the same path as that traversed by the tornado above discussed, a sharply defined column of cloud, of a leaden color rather than black, its motion being very rapidly eastward, its width being not much

more than one-fourth that in the former case—or only from two thousand to twenty-five hundred feet at most—and there was no marked electrical display in evidence. In a short time, reports came in from a little village about five miles northeast of this city, that a sudden and short-lived, but violent, windstorm had passed over the place, doing considerable damage to property, but only in a few isolated cases, and it did not seem to be recognized by any one as a tornado, but rather as an ordinary, violent wind-storm; yet, from my point of observation at such a distance that I saw the *tout ensemble*, the remarkable pillar formation of this cloud-mass, which reached to the surface of the Earth, and was clearly not an ordinary *cumulus* cloud, as well as its motion, course and the nature of the destruction wrought, (it having been only in certain spots along the course of the storm, just as would result from the dipping of the funnel in the case of a veritable tornado) clearly indicated to me that this phenomenon was also one, but of a minor type. It was undoubtedly a whirlwind with the prominent features of a tornado rather masked, as was also another windstorm that, about seven years later, passed directly over a small portion of this city, including the section in which I resided. One summer afternoon meteorological conditions were so portentous that I was led to keep a close watch upon the western sky where a disturbance was evidently brewing, although the indications were not extremely ominous. After watching for a while, outside my home, I found myself buffeted, with a remarkable and alarming suddenness, by short, violent gusts of wind, alternately warm and cold, these gusts seeming to come from every point of the compass and rendering respiration difficult; thereupon, and with surpassing fury, the rain came down in sheets, shutting out the view of all surroundings and quite bewildering me before I could regain my house, only a feet away. The wind blew with great violence, and there was a considerable fall of hail which was indicated by sound rather than by visual means, since everything was obscured by what may have been well regarded as a heavy cloud in process of rapid condensation, or precipitation, and called a "cloudburst". The storm spent its fury within ten minutes, and shortly thereafter the sky cleared and the Sun shone out revealing the fact that many trees of considerable size, with which the neigborhood then abounded, had been uprooted and leveled, a quantity of their leaves, (which were large) torn into roughly rectangular and triangular fragments— prob-

ably by the hailstones—and driven with such violence against the western side of the house that they adhered thereto for several days of sunshine and dry weather with such tenacity that they seemed to be glued to the walls. The debris, by its position on the ground, indicated distinctly that the disturbance had moved almost directly from southwest to northeast which is the course of the general average of tornadoes, while the alternation of cold gusts with warm ones, immediately preceding the onset of the main disturbance, indicated a downflow of cold dry air from above which commingling with the warm moist air at the surface of the Earth caused the phenomenally rapid condensation of aqueous vapor and copious precipitation of rain accompanied by a considerable quantity of hail. The area traversed by this storm was very restricted, the disturbance being not only local with respect to this city, but affecting only a very small section thereof which happened to be one in which my residence was located and where I observed the features of the phenomenon, which I have described above; yet it was truly a tornado but only one of a minor type like that discussed just above, and if I could have observed it at the distance, at which I witnessed that one, instead of being in *medias res* so to say—practically in the center of the disturbance —it would undoubtedly have appeared to me under similar aspects.

Another tornado of greater magnitude and involving the first set of meteorological conditions followed by the third set, passed directly over, or through, the center of this city on August 20, 1904, and wrought great destruction of property, causing also the loss of several human lives. The afternoon of that day had been rather sultry, but not so much so as was the case on July 13, 1890 aforesaid, and about 7 P. M. a very active thunderstorm set in with a magnificent and almost phenomenal display of nearly incessant lightning-flashes and almost continuous crashes and roll of thunder, the lightning-flashes, as seen against the densely black clouds, being very vivid; rain fell in torrents and all the conditions so far were those stated above as being *unfavorable* to the development of a tornado; but, after continuing nearly two hours, the thunder-storm ceased with remarkable and abnormal abruptness; an ominous calm prevailed and the clouds even parted for awhile, so that the Moon became visible, but about 9 P. M., there was heard the roar and din of an approaching tornado that had formed—as far as could be ascertained—not more than ten miles southwest of this city upon

which it descended at its very center, pursuing a northeasterly course that trended toward the north, that portion of the path directly beneath the funnel, and in which the greatest destruction was wrought—such as the complete demolition of some buildings, the unroofing of others, and the uprooting and leveling of innumerable trees, etc.,—being comparatively narrow, in some parts being not more than two or three squares, or less than 1,000 feet in width; but on either side, for a distance of perhaps a couple of miles, there was considerable destruction of a minor kind, such as the overturning of chimneys, trees, etc., the direction of the tops of the fallen trees on either side being toward the path of the funnel; but the terrific wind that leveled them, was not a part of the whirling mass of the tornado, it being only an indraft of the air at the surface of the Earth, toward the funnel, or to the vacuum produced thereby, this air being, to a certain amount—sucked upward by that vortex-tube, this being the *modus operandi* in the case of all well-defined tornadoes.

The next morning, it being clear, bright and calm, I traversed the path of the funnel, which was well-marked by the nature of the destruction wrought and the positions of the debris, making observations over about four miles of the course, within which distance was included, practically, all of the damage done although the path extended some miles farther into the country, but over that portion, this tornado had lost so much of its energy that it may be regarded as dissipated. At intervals of, roughly, between 1,000 feet and 1,500 feet along the central line, I noted the points where the funnel had dipped to, or very near, the surface of the Earth, these points being clearly indicated by the complete demolition of substantial structures, among them a span of a large steel bridge, several brick business-houses, a large church, several dwellings, and many barns, etc., as well as the unroofing of a great number of divers kinds of buildings. The funnel of this tornado passed within two hundred feet of my own residence, which was badly shaken and otherwise damaged, nearly every tree—most of them large ones,—of which there were many in the neighborhood, were leveled, thus changing the aspect of this locality; barns as well as other structures were demolished, mine falling westwardly, while one 250 feet away in that direction, was hurled eastwardly, a fact that clearly indicated that the central line of this tornado ran directly between them, about 150 feet west from the former, and eighty feet eastward from the latter, the

damage aforesaid resulting from the indraft of surface air toward the funnel.

It was in this immediate vicinity that some of the most peculiar and typical phases of tornadoes in general were exhibited, some of the noteworthy and remarkable results in this case having been shortly afterward depicted in engineering and other illustrated eastern publications. Through this locality extends a valley trending to the northwest, it being about fifty or sixty feet deep and one thousand feet wide, on the southwest rim of which stood a large dwelling-house which was lifted from its foundation, moved several feet and very badly damaged, a fact indicating that the vertex of the funnel was in close proximity to the Earth's surface, at that point. The funnel then, probably, sank into the valley, and when it reached the upper level on the northeasterly side thereof, it lifted, bodily, a substantial two-story frame house clear from its foundation, carried it some feet along the course, and then dashed it to fragments against the ground, at the same time completely unroofing a large dwelling-house on the opposite side of the street and covering the front thereof with a thick coating of mud, which fact indicates that the funnel must have been in close contact with the ground —probably when it reached that side of the valley, and rose out of the latter. The funnel must then have retracted, or shortened, because some houses directly in its path, and not more that one hundred feet from the one utterly demolished, were, practically, unscathed, the cause of this uplifting of the funnel being, according to my hypothesis, as stated above, the loss of a portion of the kinetic energy sustaining the vortex, by the discharge of electricity from the funnel to the ground, upon, and during, contact of the funnel therewith.

The truth of my hypothesis that a free discharge of electricity, in the form of the lightning-flash, between masses of cloud and air so electrified that there is set up in them an incipient vorticose motion, which may result in a tornado, acts to restore electrical equilibrium between said masses, and thereby to bring about a cessation of that motion and the dissolution of the vortex-tube if formed, was well attested by a striking phenomenon witnessed by me in the summer of 1906. One afternoon, when atmospheric conditions indicated the possibility of a meteorological disturbance of this kind, I observed, at an altitude of about fifty degrees above the horizon, almost directly west, a commotion among some masses of cloud, which were darting to and fro in a space included within angular limits of

not more than forty degrees square, the position of this area being almost exactly the same as that occupied by the minor, subsidiary disturbance that I described, on a preceding page as connected with the great tornado on July 13, 1890, and having in mind this fact I surveyed other portions of the clouded sky, but could detect no disturbance of this kind therein.

The direction of the motion of the several masses of cloud clearly indicated an incipient vorticose movement among them, but two of the larger masses, each about fifteen degrees in diameter, approached each other quite directly—one from the northward and the other from the southward—and with great interest I awaited results which, reasoning from my hypothesis in this connection, I was quite sure would be either the formation of a tornado of more, or less, magnitude, or else an electrical discharge between these two clouds, which would restore equilibrium in this regard, and cause a cessation of the incipient whirl. They approached each other with increasing velocity, and when their edges had almost come in contact, a wisp of cloud, or vapor, darted from one to the other and a sharp and peculiar flash of lightning—the shortest, I think, that I have ever seen, being considerable less than ten degrees in length—darted between them, through the wisp of vapor aforesaid, resulting in a restoration of electrical equilibrium and a cessation of the incipient vortex-motion observed, the clouds which had assumed the form of an apioid, and were comparable to the two poles of a bar-magnet, dissolving in a precipitation of rain following the loud crash of thunder that was almost immediately consequent upon the short flash of lightning aforesaid.

Not long ago there was a published report of a similar phenomenon, on a larger scale, in the case of two well developed tornadoes, not far apart, observed in Nebraska, in which a rapid play of long streaks of lightning between the two funnels was observed to have the result of dissipating these vortices.

The descriptions, above set forth, of the different types of the tornado in its divers aspects, and of the concomitant phenomena, tally with those in the case of hundreds of others that have been observed, recorded and discussed with more, or less, scientific method and accuracy, and of which many occur in some part or other of this country each year. I have cited the several particular cases aforesaid, and discussed their details at length, because they came under my direct personal observation, and have a distinct and important bearing upon the fundamental principles of my general theory, particularly in regard to the

constitution and phenomena of the terrestrial atmosphere and the effect of the solar electromagnetic radiations thereupon, as will be disclosed presently.

Another argument in favor of the hypothesis that electromagnetic action is an important factor in the generation and maintenance of tornadoes, is based upon the following facts. The electricity of atmospheric air under normal conditions, or in the absence of storms, is generally "positive", but in stormy weather it frequently changes sign, being sometimes "positive" and at other times "negative."

According to my theory in this connection, as stated in a preceding number, electrical action, or discharge, is simply a result of a disruption of the hollow, spherical molecules of gaseous matter and the dissociation of the atoms thereof which are normally in almost inconceivably rapid orbital motion around each molecular center. When each molecule possesses its normal quota of constitutent atoms, which number is equal, as I have demonstrated, to $2.\frac{d}{\Delta}$ in which the numerator (d) represents the diameter of a molecule and the denominator that of an atom, it is in electrical equilibrium, but, when the application of any force to these atoms of the molecules in electrical equilibrium, as aforesaid, is made, and additional orbital velocity is given to these atoms sufficiently great (the requisite velocity being $\sqrt{2}+$ times the normal, undisturbed, circular velocity) to throw the atoms beyond the parabolic limits, and into hyperbolic orbits, the molecule affected will be either wholly disrupted, its atoms fly-off to subsequently recombine in a normal molecule, this action constitutes an electrical discharge, and an almost continuous series of such discharges an electric current, and when only a portion of the atoms of a molecule (even only one or two) are thus affected the molecules having less than their normal quota of atoms will be *negative* with respect to those having the normal number, or an excess of atoms, the latter molecules being *positive*. Now the molecules of the atmospheric air constituting the inner portion of the funnel of a tornado being either wholly, or partially, disrupted while the molecules of the external air are practically, normal, the rapidly uprising column of these molecules parallel to the axis of the vertical funnel may properly be regarded as negatively electrified with respect to those of the outer air flowing inward to the lower part of the vacuous vortex-tube up through which they are subsequently drawn, the ascending column being comparable, or equivalent,

to an electric current flowing vertically upward from a lower positive pole, to a higher negative one, or from the inverted vertex of the funnel to the upper broad portion of the latter where it merges into the lower level of clouds just above which the incipient action productive of a tornado takes place.

Now, according to the principles of Electro-Dynamics embodied in the well-known laws of Ampère in this connection, an electrical current flowing *upward* through a vertical conducting wire will induce lines of force surrounding the wire in horizontal circles, each having the wire as center, and electrified, movable matter will be urged along these circular lines in a direction opposite to that of the hands of a clock when the current is moving *upward* and clockwise when the flow of the current is directed *downward*, a reversal of the vertical flow inducing a corresponding reversal of the horizontal rotation around the wire; wherefore in the case of the current regarded, as aforesaid, as flowing upward parallel to the axis of the funnel of a tornado, the direction of the rotation of the latter must be from right to left, or contra-clockwise, and this has been found to be generally the case in hundreds of tornadoes, the action and results whereof have been critically and scientifically studied and recorded. This direction is the same as that in the case of the circular, or rather the vorticose, movement of the air currents around a center where the pressure of the atmosphere happens to be lower than that in surrounding regions, which area of relatively low pressure as indicated by the barometer, is generally a storm-center, and is briefly denominated by meteorologists, and inscribed upon weather-maps, as a "low", in toward which the surrounding air, by reason of its higher pressure, flows according to well-known principles of hydromechanics.

This contra-clockwise direction of the flow of air in this case obtains only in the northern hemisphere and to the south of the equator, the direction is from left to right, or clockwise, the philosophical principles involved in this matter and governing the direction, being the following: By reason of the diurnal rotation of our globe around its polar axis, a point on the equator, moves eastward with a velocity of nearly 1050 miles per hour while at the poles, or the extremities of the axis of rotation considered as a purely mathematical line, it reduces to zero, varying between the equator and the poles as the cosine of the latitude, the eastward motion in latitude forty-five degrees being very approximately 735 miles per hour. Now, if we regard two movable bodies, such as masses, or currents,

of air to advance toward each other, one northward from the equator, and the other southward from the polar regions, the former will retain its more rapid equatorial, eastward motion and therefore advance in that direction relative to a more slowly moving center of barometric pressure at a point in the north —in latitude forty-five degrees for instance—and be thereby deflected in a northeasterly direction instead of moving directly northward; while the polar current, with its slower eastward component of velocity, will appear to lay behind the center of low pressure aforesaid and be deflected to the southwestward instead of moving directly southward, and the two moving masses of air will not approach each other centrally, or in direct lines toward the "low", but will form a couple that will revolve, or move with a vorticose motion, around that center, the direction of this motion in the northern hemisphere, being from left to right, or contra-clockwise. In the southern hemisphere, movements of the same kind are in operation, but, obviously, in this case the direction of rotation of the air around the center of the area of low barometric pressure, or the *true cyclone* in the easterly half whereof *tornadoes* are formed (generally in the southeastern quadrant) by the subsidiary process aforesaid, must revolve in the opposite direction, from left to right, or with the hands of a clock. The above stated principles are embodied in the well-known Buys–Ballot's "law of the winds," which fully and satisfactorily accounts for the direction of rotation of the air around the center of low barometer, but this law does not govern in the case of the rotation of the air in a tornado, around the partial vacuum within the funnel, by reason of the following facts: The air currrents moving in toward the center of an area of low pressure in the case above discussed, move, over distances of 600 to 1200 miles, or more, or over 10° to 20° of latitude, and the differenee between the cosine of the latitude of the northerly current and that of the southerly is a measure of the amount of deflection; but tornadoes are all generated in air that is, practically, calm, this being a characteristic and essential feature of this phenomenon, and the currents converging toward the center of the vacuum in this case move over a distance of only a mile, or two, or through only a few minutes of arc in latitude, so that the difference between the cosines of the latitudes in this case is practically, too small to cause the deflection, which operates in deciding the direction of rotation under the aforesaid law of Buys–Ballot, it being, in most cases, less than the thousandth part of the difference in the case of the

true cyclone, or general storm-center above discussed; moreover, the great, whirling dust-storms of the desert of Sahara, of the great Arabian desert, of the plains of India are of the same nature as the tornado, and the direction of rotation of the air currents around their axes is the same in all cases—from left to right—although the habitat of these whirl-winds is in low latitudes near the northern tropic in latitude 23° 27′ where the differences between the cosines of latitude are so small as to be, practically, evanescent, and inadequate to account for the direction of rotation.

Finally, as decisive on this point, I would cite the case of the whirling columns of sand, or dust, that traverse the desert of Kalahari in Africa, south of the equator and on the tropic of Capricorn wherein if the rotation were governed by the aforesaid law of Buys-Ballot, its direction should be from left to right, or clockwise, instead of the contrary as is the rule in the northern hemisphere, whereas this direction in the case of the whirling dust-storms is the same in the aforesaid desert region of the southern hemisphere, as it is in the northern, which, under my hypothesis of the electrical nature of the tornado, must be the case so long as the electrified current of air near the axis of the funnel flows vertically *upward*, according to the electrodynamical principles, which are embodied in Ampère's laws, thereof. If the direction of this current be reversed, so that the vertical flow be *downward* to the Earth's surface, as must happen when the funnel is in intimate connection with the ground, a result must be a reversal of rotation if the flow be continued downward during a sufficient length of time, or, as is the case generally, a checking of the motion in the original direction, as if a brake had been applied to the whirling mass during the short periods when the funnel is in contact with the Earth, this checking of the rotation, obviously, operating to cause the retraction, or shortening and uplifting of the funnel, and, finally, the dissolution of the tornado, the nature and concomitant phenomena whereof are completely, and satisfactorily, explicable under my hypothesis in this connection, as above set forth. The structure of the funnel with its current of electrified matter flowing upward, and occasionally downward, along the vertical axis, and the rotating currents, in corresponding directions, horizontally moving parallel to the lines of force around said axis is analogous to a *solenoid* which is endowed with some of the properties and characteristics of a bar-magnet, the north-seeking pole whereof is at the upper end of the axis.

St. Paul, Minn. To be continued.

A POSSIBLE PLANET BEYOND NEPTUNE'S ORBIT.

H. C. WILSON.

For Popular Astronomy.

In the February number of Popular Astronomy, page 123, attention was called to the announcement by Professor W. H. Pickering, of a possible ultra-Neptunian planet in Right Ascension $7^h\ 47^m$, Declination $+21°$. In the December number of the *Monthly Notices* of the Royal Astronomical Society Professor George Forbes from a study of the aphelion positions of a number of comets deduces the place of a possible planet for 1908 as longitude 215° 31′, latitude —33° 53′ or right ascension $13^h\ 12^m$, declination —45°. For 1914 the predicted place is longitude 217° 21′; latitude —32° 15′, or right ascension $13^h\ 24^m$, declination —44°.

The period of the hypothetical planet is given as 1076 years and the other elements as follows :

Ω	i	e	π	Mean Distance	Date of Perihelion Passage
247° 34′	52° 0′	0.1665	114° 57′	105.1	A.D. 1702

A remarkable feature of these elements is the great inclination (52°) of the orbit to the plane of the ecliptic, which explains perhaps why it has not been found if it should be bright enough to be readily seen or photographed.

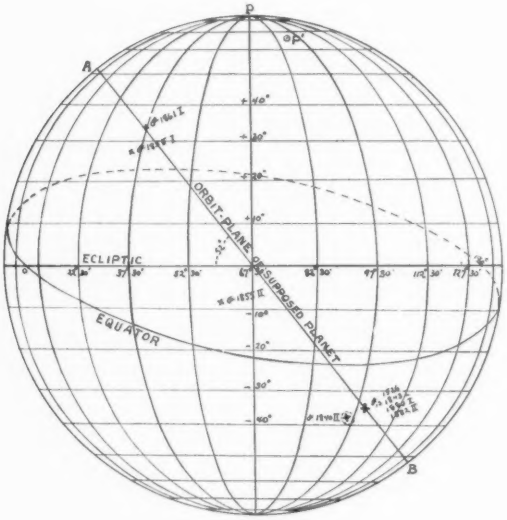
In the accompanying diagram, I have endeavored to place before the reader's eye the relative positions of the orbit of the suppositious planet and the aphelion points of the comets upon which Professor Forbes bases his prediction of the planet. The orbit of the planet is represented as in a plane perpendicular to the plane of the paper, and having its descending node at longitude 67° 30′, projected upon the center of the celestial sphere.

Professor Forbes finds seven comets, of those appearing during the past century, which have their aphelion distances approximately 100 times the Earth's distance from the Sun. Out of these seven aphelia four, are found to lie almost exactly on a great circle as shown in the diagram and the other three lie only a little to one side of that circle. The four are the comets 1843 I, 1880 I, 1882 II and 1861 I. The aphelia of comets 1840 IV, 1855 I, and 1855 II lie to the left of the circle, but near enough to suggest their possible capture by the planet.

The three comets 1843 I, 1880 I, and 1882 II have almost exactly the same aphelion direction, and the uncertainty of their elements leaves it quite possible that their distances at aphelion

are the same. Again Professor Forbes finds that the comet of 1556 has the same aphelion direction with these and the uncertainty of its elements allows the distance to be the same. He suggests therefore that the three more recent comets may have resulted from the disruption of the comet of 1556 by a planet when that comet was at aphelion in about the year 1702.

"The comet of 1556 was supposed to be identical with the comet of 1264 and its return about the year 1848 was confidently predicted, especially by Hind."



"Now if the non-appearance of the comet in 1848 as expected was due to a complete change in its orbit by the perturbations of an unknown planet, it is certain that this would be most likely to happen at or about its aphelion position, which in normal conditions it would reach in the year 1702 A. D."

In order to fit the planet's orbit to the aphelion of the comets Professor Forbes finds it necessary to give it a large eccentricity (about one-sixth), so that its distance from the Sun varies from 87.5 at perihelion to 122.6 at aphelion. Calculating the dates at which the comets and the planet should have been in the same longitude, he finds the remarkable agreement shown in the following table :

Comet	Aphelion. Long. (Orbital.)		Lat.		Aphelion Distance Calculated.	Assumed.	Date Aphelion.	Date for Planet in Same Long.	Radius Vector of Planet.
	°	′	°	′			A.D.	A.D.	
1556 }									
1843 I }	114	57	0	0	87.52	87.52	1702	1702	87.52
1880 I }									
1882 II }									
1861 I	24	6	0	0	110.36	110.36	409	409	102.7
1840 IV	196	6	+ 0	13	97; 97; 101	99.70	821	821	99.88
1855 I	40	17	— 4	34	206; 124	147.27	1532	1533	
1855 II	69	55	—11	18	124	125.75	1604	1604	

I am unable to verify the orbital latitude as given for comet 1840 IV. From the diagram, this would appear to be about —6°, instead of +0° 13′, if the heliocentric latitude and longitude of the aphelion given by Professor Forbes are correct.

The present place of the planet as predicted by Professor Forbes is very close to the place of comets 1556, 1843 I, 1880 I and 1882 II, as projected on the diagram but, on the farther side of the sphere in longitude 215° instead of 101°. Its motion will be upward and toward the left. On the star maps the position is about two degrees northwest of the great star-cluster ω Centauri.

"When searching for the planet, it must be remembered that probably the orbit is subject to less uncertainty than the epoch, and the search should be extended forward and backwards on the line indicated."

In commenting upon a report of this matter at the meeting of the British Astronomical Association, on Dec. 30 last, Mr. Hardcastle said that Professor Forbes had tested his method of discovering planets by carrying out the same argument precisely for the Neptunian family of comets. The discussion led him to assert that Neptune's longitude in 1880 must be 45°—it actually was 48°.

Mr. A. C. D. Crommelin at the same meeting said that "Professor Forbes had made a case for the hypothetical planet, but he (the speaker) did not feel absolutely confident that it had a real existence. There seemed to be one weak point in it. Professor Forbes laid great stress about the direction of the aphelia of the three comets of 1843, 1880 and 1882 being the same, and he said these three comets were together at their last aphelion; but since their perihelion distance was the same, and since he postulated that their aphelion distance was also the same, then their periods (which depended only on the major axes of their orbits) should all be the same, yet the semi-periods differed, roughly, 40 years, which was a considerable fraction of their whole period. Consequently the only way they could get out

of it was by supposing that one component was going out to aphelion at the time of the change of orbit, and another fragment was coming in from aphelion. By that means they could account for the times of their coming to perihelion, but they lost the point which Professor Forbes made of their aphelia all lying in the same direction. They could not have aphelia in the same direction and the comets be simultaneously in aphelion, and that weakened Professor Forbes' case. The orbits of all these comets were well determined and the directions of the aphelia were well-known, (they were diametrically opposite to the perihelia), that seemed to him to make it very unlikely that the separation took place so recently as the last aphelion. He had little doubt that these three comets were once a single comet, but he would put the disruption a great deal further back than 200 years ago. Otherwise he could not see how they could all have the same major axis and yet times of perihelion differing by 39 years." Mr. Crommelin also pointed out that Professor Forbes had found too many comets approaching the same slow moving planet, more than belong to either the Uranus or Neptune families of comets. This planet being so far out from the Sun and moving in so large an orbit would be less likely to encounter many comets than would the planets nearer the Sun.

GRAVITATION.*

CHARLES MORRIS.

Of the many problems with which science has had to contend in the recent centuries, that concerning the origin of the force of gravitation has proved by far the most difficult to solve. There is no other problem in which some progress towards a definite solution has not been made, but the question of gravitation remains practically in the position which it attained more than two centuries ago, when Sir Isaac Newton discovered its law of operation and offered a suggestion as to its probable cause. Many other hypotheses regarding it have been propounded since his day, but none of them have proved more satisfactory than that of Newton himself, and to-day the problem of gravitation remains in the precise state in which he left it,

* *The Journal* of the Franklin Institute, March, 1909.

namely, that attraction as a force inherent in matter cannot exist, and that the gravitative force is probably in some way due to the action of an ethereal medium in contact with matter.

All the theorists, since Dr. Hooke in 1671, have employed this conception, and though none of them have succeeded in attaining the desired result, the impression is general among physicists that the basis of their arguments is correct. If, indeed, we deny the possibility of attraction, of the exercise of force by a body upon some distant body, of "action at a distance," as it is termed; we are obliged to accept the only alternative, that all exercise of force must come through actual contact. And as there is no visible substance in contact with matter to which the force of gravitation can be ascribed, we are obliged to suppose the existence of an invisible one. And this must be an universal one, if, as is believed, gravitation is an universal force. Such an agent would probably resemble in some or all respects the hypothetical luminiferous ether.

There seems no escape from this conclusion. We are aware that matter exists in a state of compression, and that its masses and particles alike manifest a tendency to move towards each other. If we deny that this is due to the agency of an inherent attractive force, we must look elsewhere for an agent capable of producing the effect. Such an agent, it would appear, must be some force-exerting substance in contact with matter, such, for instance, as the luminiferous ether, the assumed conveyer of the waves of light and other vibratory impulses. To this ether, or to some ether better adapted to the purpose, all theorists have turned in their attempts to solve the mystery of gravitation. Yet if the luminiferous ether fills all space, as is claimed, it is highly improbable that there is a second ether coördinate with it. At all events it is unphilosophical to seek for such a second ether until it has been shown that the ether of whose existence we have some evidence from the radiant phenomena of nature has been proven incapable of performing the necessary functions. In place of conceiving of a special ether as the agent in gravitation, it seems more logical to credit the ether which science so widely accepts with properties in addition to those usually ascribed to it, yet in accordance with its nature, and seek to discover if any such conceivable properties may afford an explanation of the phenomena of gravitation.

This has been attempted without success by many physicists. Yet, as there is no evidence that nature possesses any other agent capable of producing the observed results, the impression

is somewhat general that gravitation must be a result of some activity in the agent to which is attributed the conveyance of the rays of light. Of late years there has been a tendency to ascribe the gravitative effect to some involved or intricate mode of ether motion. Yet the probability of this we may justly doubt. This is not the nature's method of action. Its great results are produced by simple and direct means. It thus appears logical to assume that this, the greatest and most general of all its processes, the one upon which the very existence of the material universe, as known to us, appears to depend, is the outcome of some such simple agency, not improbably the presence in the ether of some of the ordinary modes of motion which are visible or supposable in ordinary matter.

If we dismiss attraction as a force agency—as scientists very generally are disposed to do—we seem obliged to turn to the motion of some substance as the sole agent of force. At least the only agents suggested in all the years of scientific speculation on this subject have been attraction and motion. Each of these, acting from some substance, would be capable of exerting a compressive influence upon other substance, and we can conceive of no other agency competent to this effect. If attraction be dismissed motion alone remains, its force consisting in the momentum residing in some moving body.

Assuming then, in our study of gravitative phenomena, the necessary existence of an ether with properties adapting it to the purpose, the character of these properties comes next in question. The ether action can take only one of three forms; it must operate as a traction, a propulsion, or a pressure. Of these, traction—a drawing influence exerted upon matter by intermediate substance—has been avoided by theorists, none of them being able to suggest an effective mode of action of this kind. Propulsion—the force of impact— has been considered from various points of view, but ineffectively. Pressure has also been considered by theorists, with like unsatisfactory results. Yet from what we know of the phenomena in general, and of the progress of theory upon this subject, the latter seems the most probable and promising of the three methods.

Such is the status of the problem as it exists to-day, the foundation upon which any further study of the nature of gravitative force must be based. Newton's idea of the rarefaction of ether around masses of matter and a consequent pressure; Le Sage's conception of a second ether, consisting of swift moving corpuscles, acting through impact; Dr. Young's conception of the

repulsion of ether by matter; and the many other hypotheses which have been propounded, have all been dismissed as inadequate, and all we have reached is the general proposition that gravitation is due to the action upon matter of some external energy, this presumably arising from some mode of motion in the luminiferous or other ether.

Before proceeding further two things must be considered: what modes of motion of a general or universal character are known to exist; and what do we know of the constitution and capabilities of the ether. In matter we are aware of only two general modes of motion, the direct motion of gaseous molecules, and the vibratory motion attributed to the molecules of solid material—the latter varying into curvilinear and circular motion. Ether, so far as hypothesis concerning it has gone, possesses but one mode of motion, the vibratory, the to-and-fro swing of its particles which is supposed to be the agency in light and other radiant manifestations. The assumption is that the ether particles are fixed in space and possess no direct motions, not darting about in the free and irregular manner attributed to gaseous molecules, but restricted to vibratory movements like those of the molecules of solid matter. Were the former the case, the motions which produce the phenomena of light would be dissipated and the transmission of light waves through space could not proceed. For this reason physicists hold that the ether must be similar to solid matter in its constitution or state of aggregation.

Of the other conditions of ether we know very little. It is regarded as a substance of extreme tenuity, and yet exceedingly rigid; as incompressible and yet highly elastic. Some maintain that it exists as a plenum, filling space to its full capacity, and yet possessed of a yielding capacity, so as to permit vibratory movements. Yet these suppositions seem to impose upon it irreconcilable conditions, and the fact that it admits of vibration renders it very probable that it possesses separate corpuscles, however minute, with space for them to move in, however contracted. That it is highly susceptible to movement we know from the freedom with which it responds to radiant impulses, and from this we may deduce the probability of its possessing movements native to itself, in addition to those impressed upon it by matter.

If ether be the seed stuff of matter, as is widely believed, it is reasonable to conclude that, as matter has absorbed only a minor portion of the substance of ether, so it has absorbed only

a minor portion of its motions or activities. In such case it may possess active native motions and inherent energy of great intensity. Such would be necessary to make it the agent in the phenomena of gravitation.

If this be granted as probable, if ether does possess such a native mode of motion, of universal distribution, as contrasted with its partially distributed radiant motions, what is likely to be the character of this motion? The condition of the ether held to be requisite for the transmission of light, that is, the confined state of its particles, would appear to be preventive of any general movement through space, any power of direct transmission from place to place, and permit only some form of vibratory motion. And we may deduce from the fact that the molecules of each portion of matter vibrate at a fixed pitch, dependent upon their mass and condition, that the same is likely to be the case with the corpuscles of ether; since, in contrast to transitory vibrations, any native and persistent vibrations must be governed in rapidity by the constitution of the substance in which they exist.

Solid matter is capable of transmitting the vibrations of sound; but these, being at a pitch different from that normal to the molecules, are not absorbed by these. May not a similar condition exist in the ether? May not the radiant vibrations, at a great variety of pitch, impressed upon it by matter, similarly pass through it without absorption, while it has a persistent vibration of its own, at the pitch normal to its density? If the ether possesses any native motion at all, this is the form it must inevitably assume, supposing it to have the constitution usually attributed to it.

Let us assume the possibility of the existence of such an ether, filling all space not occupied by matter, capable of receiving vibratory impulses from matter and transmitting them intact to distant matter, and at the same time having vibratory motions native to itself and affecting its entire substance persistently. What deductions can we make from such a hypothesis? To be vibratory such an ether must be elastic. And if vibratory and elastic we cannot escape the conclusion that the corpuscles possess minute areas in which they move and to which they are confined. The density of such an ether would be due to its total quantity as compared with the area of space which it occupies in the universe. If its quantity be insufficient to fill this space absolutely there must be intervals, however minute, between its particles, and these would serve as areas of movement. The

very rapid motion of the particles would enable them to keep these areas practically occupied and also would give rise to a homogeneous density throughout, except where the presence of matter might affect the density.

If we may assume these premises to be correct, the ether would be incompressible only in this partial sense, it being everywhere compressed to the limit of its elastic powers of resistance. Returning now to the question of vibration, how shall we comprehend the to-and-fro swing of particles of either matter or ether, if the seeming force of attraction be disregarded? If attraction is absent, what is there to hold the particles in restraint and prevent them from moving straight onward and escaping to new localities? To convert such a power of onward movement into a vibration there must be a controlling agency of some kind present. If it be not a power within the particle, it must be a condition without it. Can we imagine any such condition? It may be that we have one in the elastic resistance of the surrounding ether. Taking the case of a single vibrating corpuscle, we can readily conceive of its swinging into a nest of resisting ether, as fixed in place as itself, compressing this in doing so, and being driven back by its elastic expansion, to be similarly checked and driven back at the opposite extremity of its swing. Forced back with accelerating rapidity to the center of its field, it would be again checked and brought to rest by a similar agency in its other phase of vibratory movement, the process being indefinitely repeated.

What becomes of the lost motion of the particle when thus brought momentarily to rest? We are not prepared to accept the ordinary explanation of potential energy, a hypothesis widely used in science to explain phenomena of this kind, but which is purely metaphyscial and absolutely without demonstration. A more logical explanation would be that the lost motion of the corpuscle is taken up by the resisting ether, which in its elastic reaction yields reverse motion of its own to the vibrating corpuscle.

We cannot well avoid this conclusion. If we discard the idea of an inherent force of attraction in matter, and decline to accept the questionable potential energy, the only conceivable other source of the loss and gain of motive energy by the corpuscle must be the action of some external motive energy, which in this case might well be that of the elastic resistance of surrounding ether. Certainly it is not easy to imagine any other.

Leaving this phase of the subject and coming to the considera-

tion of motion in its general aspects, the dictum of science is that all motion is normally persistent in force and direction. As no mass at rest can move of itself, so no mass in motion can lose or gain speed or change in direction of itself. Such changes can arise only from the action of external agents, and every change produced by these agents is compensated by an equal opposite change in themselves. Thus in the case of atmospheric molecules, which come into contact with each other thousands of millions of times every second, the motion of each molecule being incessantly diverted, the separate lines of motion, and the energy displayed in each, are never lost. They are simply transferred to other molecules, and pass unceasingly onward through space, being conveyed by myriads of molecules with the same effect as if they were conveyed by a single one.

This principle applies not only to free-moving particles, but to vibrating ones as well. We cannot imagine that the energy of the vibration is annihilated when the particle comes to rest at the extremity of its swing and new energy created when it returns. Nor can we logically imagine that the motion is temporarily changed into some condition of non-motion, as the hypothesis of potential energy demands. We therefore seem obliged to accept some such hypothesis of external influence as that suggested above, in which a compressible resisting substance takes up the lost motion, and by its elastic rebound imparts a reverse motion to the vibrating particle. In the case of vibrating ether corpuscles the surrounding ether may well be competent to perform this function. In the case of material molecules the surrounding ether may possibly perform the same function, the surrounding matter, presumably not in contact with them, being incapable of such an elastic function. In such a case the ether would act as the agent of a force analogous to that of gravitation so far as the particles of both matter and ether were concerned.

In fact, within the hypothesis here presented, if carried to its ultimate, may perhaps lie the solution of the whole problem of gravitation. This is the subject which we have next to consider. The motion of the vibrating ether corpuscle, when transferred to others, cannot vanish or lose any of its energy. It must pass onward by interminable transfers from particle to particle. Thus we may consider space as being incessantly traversed by lines of motive energy, passing in every direction, unaccompanied by transfers of material, yet persistent in force and direction. In this transfer of energy matter and ether might both take

part, though the ether, by virtue of its vastly greater space occupancy, would be the principal agent. It is adapted to this function by being highly susceptible to motive influences, and probably, like matter, normally in incessant motion.

The vibratory activity of the ether, thus formulated, would, as just stated, be far more than a local vibration. It would constitute a wave motion incessantly traversing space, analogous to the waves of light vibration, but differing from the latter in being longitudinal instead of transverse. Each vibrating corpuscle would cause a condensation of the ether into which it moved. this being followed by a rarefaction as it was elastically driven backwards, the energy embraced in its every swing being taken up by the resisting corpuscles, and in turn transferred by them to new corpuscles, thus passing indefinitely onward. There would thus arise a condensational-rarefactional wave like that of sound, differing from the latter principally in its agent and its vastly greater rapidity.

These lines of energy would not necessarily be confined to the ether but might traverse the particles of matter which they encountered in their course, their speed diminishing to correspond with the mass of these particles but their momentum remaining the same. And here the significant fact presents itself that wave motions of this type are of a kind adapting them to traverse matter in all its states, solid, liquid and gaseous alike, with equal facility, and ether also in all the states it is likely to assume. While transverse undulations, like those of light and radiant heat, are restricted to substance in the solid state of aggregation, longitudinal undulations have no such restriction, but are fitted to all known conditions of substance.

In a glance back at what has thus far been stated, it is apparent that this hypothesis adds nothing to the characteristics of ether assumed or conjectured to exist except the suggestion that, in addition to its radiant waves, it is in a state of incessant vibration, at a rate normal to its constitution, this yielding a system of longitudinal waves which in their out-flow may be capable of traversing ether and matter alike. There is nothing revolutionary in this suggestion. If the ether possesses any native motion at all, as is highly probable, this is the form it is most likely to assume, a mode of motion distinct from that of its radiant waves and therefore not likely to interfere with the latter. Yet in the incessant and universal transfer of energy through space which this hypothesis suggests nature may possess an agency of remarkable power and efficiency. On ether

itself this transfer of force would, with its compressive action, produce an effect resembling that of gravitation. On matter it may perhaps serve as the agent in all the phenomena of gravitation.

The material spheres, which, at vast distances asunder, are distributed like floating islands in the ocean of ether, are likely to be acted on by its energies, whatever form these may take. We perceive them affecting ether by their motions and producing in it a great variety of radiant waves. May not the ether in turn affect these spheres of matter by its normal motions and produce some equally marked effect upon them? Permeated as they are by the ether, which acts upon their every atom and every electron, we may justly suppose that there will be varied phenomena of action and reaction between these diverse forms of energy-containing substance. Some of these phenomena are apparent to us in the rays of light and heat, which arise from the energies of matter. It is very probable that there may be others, as yet unknown to us, arising from the energies of ether. It is with the latter that we are here concerned.

Returning to the form of universally transmitted energy which we have above attributed to the ether, it is in order to consider what effect it is likely to produce upon matter. If this energy were met by an equal resisting energy in matter, an exact balance of force would exist between the two types of substance. If unequal in energy, as is most probable, the stronger would exercise some degree of control over the weaker. If the ether energies were the stronger, the resulting conditions might well be those of gravitation. In such a case the great body of ether surrounding and permeating every sphere of matter, and acting upon it with the full vigor of its native energies, might produce a compressive effect upon the sphere as a whole and upon its every part, and if the ether energy were sufficiently superior in force might bring about the spherical condensation which we perceive. We are not dealing here with any form of impact of moving ether, but with the force of transmitted vibrations of stationary ether, impinging incessantly upon the bodies of matter, and exerting a compressive influence upon them.

Let us consider any such body of matter acted upon on all sides and through all its substance by lines of force emanating from the boundless sea of ether, through the agency of the ether corpuscles in immediate contact with the material particles. This surrounding ether, if superior in energy to the matter acted upon, must exert a compressive effect, which we may here view in the

separate cases of the three forms of matter. The resisting energy would be that of the molecular movements of matter, and if these be reduced by loss of heat the molecules might be pressed together so energetically as to cause them to enter the solid state. If, on the contrary, the heat energy of the molecules be increased the opposite effect would appear, they growing forcible enough to overcome in part the ether forces and break loose from their vibratory subjection into the freer mode of motion of the liquid. Still greater heat might enable the material to expand against the compressing force until it assumed the freedom of the gaseous state. Yet as the expansion of the gas would subject it to the compressive action of a much wider volume of ether, its molecules would still be held in partial captivity, and would need a much greater energy of motion to enable them to escape into cosmic space.

We are here brought back to our original premise, that if the compression of matter is not due to internal attraction, it must be due to external pressure. We have credited the ether with native energies under conditions that enable them to act incessantly upon matter, with the probability that they would exert the requisite compressive force. But there are other phenomena in gravitation than that of mere condensation, and no hypothesis can be regarded as tenable until it has been put to the test of explaining all the phenomena. To deal with these we must begin by taking the case of some single sphere, such as the Sun, and seeing what probable effects such lines of ether energy would produce in it, beyond that of mere consolidation.

We know that the Sun is a very porous body, containing far wider areas of space than of matter, its particles being very minute as compared with the space surrounding them, and are satisfied that it is everywhere permeated by the rare ether, which comes into contact with its every particle and is in position to act upon every portion of its substance. As a result there seems likely to be a continual action and reaction between them, an unceasing conflict between their respective energies. If, now, as premised, the energies of the ether be superior in force, the particles of matter would be driven together until their aggregated energy enables them to prevent further condensation. Part of the ether energy would be employed in maintaining this state of compression, part of it would be taken up by the molecules and be transferred by them to the ether beyond, enabling it to act upon more interior molecules. Thus the ether would lose energy only to the extent that it exerted a moving or controlling force upon

the particles with which it came in contact, its surplus energy passing forward through the intermediate matter to the ether beyond, to be there again employed. The compressing force must be continually exerted, since any diminution in it would be attended by an immediate expansion in the molecular groups, and any cessation by an explosive outflow of the molecules. Hence a continuous re-enforcement from external forces of the ether energy would be necessary and this re-enforcement would be constantly supplied.

The conclusion to which this line of argument leads is the following: The loss of energy by the ether through its action upon matter would by no means be total. A portion of it would be absorbed by the matter acted upon, while the remainder would be transmitted by aid of vibrations of the material particles to the ether beyond, much of the ether energy in this way traversing the solar mass. As a final result, the lines of force which penetrated the Sun and emerged upon its opposite side would have lost much of their energy and be weakened to the full extent of the work they had performed, becoming much less effective than the fresh volumes of ether energy flowing in from space upon the opposite side of the sphere. As they have been engaged in producing and maintaining the condensation of the solar substance, they have decreased in energy accordingly.

If the probable existence of such a state of affairs be admitted, it leads to conclusions of the highest importance. At every point on the Sun's surface there would be an inflow of ether energy in full force, and an outflow of similar energy reduced in force to the extent of the internal work performed, the difference between these two sums of energy constituting the effective gravitative force at that point. Everywhere within the interior the same principle would apply, every internal molecule being differently affected upon its two sides, except those at the center, where the inflowing volumes of gravitative force would become equalized. Everywhere else they would be impelled towards the center. We would have here an effective mechanism, and one producing no heating effect upon matter, as in the case of the impacting corpuscles of the La Sage hypothesis, since only that portion of the energy is absorbed which is necessary to maintain the gravitative compression.

The loss of ether energy here demanded would be analogous to the loss of heat energy by matter when it performs work, so that we may speak of the difference in condition between the inflowing and outflowing lines of ether force as practically a dif-

ference in temperature. But the point which it is especially desired to make here is that the decrease in energy of the outflowing ether must persist in the ether waves, or lines of vibration, as they flow swiftly outward through space, and may continue unchanged not only throughout the solar system but to indefinite distances beyond. As a result the Sun would be surrounded by an ether atmosphere traversed in every direction by rays of vibratory energy of which those flowing inward toward the Sun would be far more energetic than those flowing outward from it.

It is this ether atmosphere that the Earth and all the planets swim in. In consequence, the inflowing ether energy would act upon them much more vigorously than the outflowing, the difference in propelling force being sufficient to give each of their molecules a slight set inward toward the Sun, or, collectively, to impel the planetary mass as a whole in this direction, the agency affecting the planets being thus similar to that affecting the solar molecules. On the other hand, each planet would act similarly upon the ether and react upon the Sun in the same manner, every cosmic body having an ether atmosphere of this kind effective upon other bodies in accordance with its mass and distance. At every greater distance from the Sun or planet, the volume of its weakened ether would occupy a greater spherical area, increasing, as could be geometrically demonstrated, in the proportion of the square of distance, the gravitative effect therefore weakening in exact conformity with the Newtonian law of gravitation. In this hypothesis, as will be perceived, we are not dealing with a shadowing of one sphere from ether impact by another, as in the Le Sage hypothesis, but with a permanent condition of the ether surrounding each sphere and affecting every mass of matter within its influence with a force dependent upon its distance.

The hypothesis here presented has a special significance, as it offers a solution of the most difficult problem in the phenomena of gravitation, one which no previous theory has even attempted to explain. This is that of the instaneous transmission of gravitative force, its apparent passage over enormous distances in infinitesimal periods of time. Under the present hypothesis this abstruse problem vanishes. There is no transmission of force to be dealt with. If the ether is permanently affected around every cosmic body, each mass at any distance from it must at every instant be subject to the gravitative force suitable to that distance, and in any change of distance feel a similar instantaneous effect as it entered a new region of the spheral atmosphere.

There is another important problem in the relations of ether and matter that must be here considered, that of the movement of the spheres through the ether without evident obstruction. The theory that the ether exists in the solid state adds to the difficulty of this problem. It is gravely attempted to be explained on the basis of the fact that a weight will pass through a jelly without leaving any trace of its passage. The ether is compared to a jelly of extreme thinness. But as no weight can sink through a jelly without obstruction and loss of speed, the parallel does not hold good, or would not unless the ether was of infinite thinness, a condition which we cannot predicate of any cosmic substance.

Under the present hypothesis, however, this problem assumes a different aspect. The ether is not passive in its action. It exerts a force on the moving Earth which might be highly obstructive to movement but for the fact that it acts with equal energy on every part of the surface, the lines of ether energy being as effective on the receding as on the advancing side of the Earth in its orbital movement. Any increased pressure of the ether due to the Earth's forward movement would be balanced by an equal increased reaction of the Earth. And any decreased ether pressure on the receding side would be similarly balanced by a like decreased reaction of the earthly material. Thus it would appear that the variations in Earth and ether action would be in exact balance and a moving sphere bear the same relation to the ether as a sphere at rest.

In conclusion it may be said that, under the terms of this hypothesis, the force of gravitation is only a portion, possibly a small portion, of the total energy of the ether, it being simply the difference in energy between the lines of ether energy that have been partly exhausted within a sphere and those of external ether. If we take the example of the molecules of the atmosphere, we would have the effect upon them of opposite lines of force: one series weakened by passing through the sphere, the other series in full strength; one pressing upward weakly, the other pressing downward strongly. The result would be the difference in energy between these two forces. The difference will increase the larger the sphere and the greater the internal work done. Thus, though the inflowing ether pressure on the Sun would be the same as on the Earth, the gravitative pressure would be much greater, on account of the greater enfeeblement of the ether that had traversed the Sun. In open space the condensation of the ether is probably uniform, a fixed balance existing between the energies of compression and expansion. This balance may be disturbed by contact with matter, since there is reason to believe that the ether grows more dense in the interior of transparent bodies, where it meets with a diminished resistance. The ether which has penetrated a sphere would also probably be denser, from its fall in temperature or loss of energy and its consequent diminished power of resistance.

To be continued.

PLANET NOTES FOR MAY, 1909.

Mercury will be at greatest elongation east from the Sun 22° 23′ on May 20, and will be easily seen as evening star for a week or more.

Venus, having been at superior conjunction April 28, will be invisible during the greater part of May.

THE CONSTELLATIONS AT 9:00 P. M., MAY 1, 1909.

Mars will be at quadrature, 90° west from the Sun on the morning of May 13, and so may be seen best in the morning hours just before dawn. The planet will be in the constellation Aquarius and recognizable easily because of its ruddy color and its brightness as compared with the stars in that region of the sky.

Jupiter will be at quadrature, 90° east from the Sun on May 26. The planet is visible toward the west during the evening, and is much brighter than the stars around it, in the constellation Leo. On May 1, Jupiter will be stationary in right ascension, having reached the western end of its path for this year, and from now on for several months will move eastward.

Saturn is morning star, but is still too close to the Sun to be observed.

Uranus is in the constellation Sagittarius, and may be found, with the aid of a good telescope, during the latter half of the night.

Neptune is in the constellation Gemini a little over a degree northeast of the star ζ. It may be found in the evening with the aid of a large telescope.

Occultations visible at Washington.

Date 1909	Star's Name	Magnitude.	IMMERSION. Washington M.T. h m	IMMERSION. Angle f'm N. °	EMERSION. Washington M.T. h m	EMERSION. Angle f'm N °	Duration. h m
May 3	598 B. Virginis	6.1	10 36	72	11 26	1	0 50
4	6 B. Librae	6.2	7 31	95	8 34	329	1 03
4	μ Librae	5.4	16 38	120	17 42	277	1 04
7	39 Ophiuchi	5.1	12 20	163	13 09	236	0 40
7	191 B. Ophiuchi	6.3	16 34	55	17 34	315	1 00
7	*b* Ophiuchi	4.4	17 41	13	17 53	354	0 12
8	67 B. Sagittarii	6.4	13 49	80	15 11	296	1 22
14	33 Piscium	4.7	16 32	354	16 56	311	0 24
21	5 Geminorum	5 9	7 26	66	8 17	301	0 51
21	8 Geminorum	6.1	9 37	166	9 52	200	0 15
22	48 Geminorum	5.8	8 57	183	9 05	198	0 08
31	4 G. Librae	6.5	10 35	151	11 51	275	1 16

Phenomena of Jupiter's Satellites.

Central Standard Time, beginning at noon.

	h	m					h	m			
May 2	7	42	IV	Sh.	In.	May 14	7	13	I	Oc.	Dis.
	9	42	II	Oc.	Dis.		10	44	I	Ec.	Re.
	11	43	IV	Sh.	Eg.	15	6	52	I	Tr.	Eg.
4	6	41	II	Tr.	Eg.		8	06	I	Sh.	Eg.
	9	04	II	Sh.	Eg.	18	8	52	II	Tr.	In.
5	7	12	II	Oc	Re.		11	27	I	Sh.	In.
	8	41	III	Ec.	Re.		11	44	II	Tr.	Eg.
	10	52	I	Oc.	Dis.	19	11	24	III	Oc.	Dis.
	11	52	II	Ec.	Re.	20	9	18	II	Ec.	Re.
6	8	12	I	Tr.	In.	21	9	07	I	Oc.	Dis.
	9	24	I	Sh.	In.	22	7	43	I	Sh	In.
	10	31	I	Tr.	Eg.		8	45	I	Tr.	Eg.
	11	43	I	Sh.	Eg.		10	01	I	Sh.	Eg.
7	8	49	I	Ec.	Re	23	6	40	III	Sh.	In.
9	12	08	II	Oc.	Dis.		7	08	I	Ec.	Re.
10	10	40	IV	Oc.	Re.		9	59	III	Sh.	Eg.
11	8	50	II	Sh.	In.	25	11	28	II	Tr.	In.
	9	12	II	Tr.	Eg.	28	11	01	I	Oc.	Dis.
	11	40	II	Sh.	Eg.	29	8	21	I	Tr.	In.
12	7	31	III	Oc.	Dis.		9	37	I	Sh.	In.
	11	01	III	Oc.	Re.		10	40	I	Tr.	Eg.
13	6	43	II	Ec.	Re.		11	56	I	Sh.	Eg.
	10	04	I	Tr.	In.	30	8	56	III	Tr.	Eg.
	11	19	I	Sh.	In.		9	05	I	Ec.	Re.
	12	23	I	Tr.	Eg.		10	40	III	Sh.	In.

Note.—In., denotes ingress; Eg., egress; Dis., disappearance; Re., reappearance; Ec., eclipse; Oc., occultation; Tr., Transit of the Satellite; Sh., transit of the shadow.

COMET NOTES.

Elements of Comet *c* 1908 (Morehouse).—In the Drake Observatory Bulletin No. 1, Messrs. D. W. Morehouse and P. F. Whisler give elements of Comet *c* 1908, computed from the observations,

1908 Gr. M. T.	α h m s	δ ° ′ ″	Observer
Sept. 14.55340	2 8 58.45	+73 45 37 07	Metcalf
Oct. 13.34367	19 34 02.37	+53 22 07.62	Morehouse
Nov. 11.59784	18 52 43.02	+ 9 42 20.5	Morehouse

ELEMENTS.

$T = 1908$ Dec. 15.7696 Gr. M. T.
$\omega = 171° 27' 34''.9$
$\Omega = 103\ 06\ 58\ .5$
$i = 140\ 10\ 43\ .2$
$\log q = 9.976317$

The Bulletin contains nine other positions of the comet.

VARIABLE STARS.

Minima of Variable Stars of the Algol Type.

[Given to the nearest hour in Greenwich Mean Time beginning with noon. To reduce to Central Standard time subtract 6 hours, or for Eastern time subtract 5 hours.]

U Cephei

d	h
May 3	5
5	17
8	5
10	16
13	4
15	16
18	4
20	16
23	4
25	15
28	3
30	15

RZ Cassiop.

d	h
May 1	18
2	23
4	4
5	8
6	13
7	18
8	22
10	3
11	8
12	12
13	17
14	22
16	3
17	7
18	12
19	17
20	21

RZ Cassiop.

d	h
May 22	2
23	7
24	11
25	16
26	21
28	1
29	6
30	11
31	15

RX Cephei

d	h
May 21	8

RS Cephei

d	h
May 5	4
17	14
30	0

RY Aurigæ

d	h
May 3	3
5	20
8	14
11	7
14	1
16	18
19	12
22	5
24	22
27	16
30	9

RZ Aurigæ

d	h
May 2	12
5	12

RZ Aurigae

d	h
May 8	12
14	13
17	14
20	14
23	14
26	15
29	15

RW Geminorum

d	h
May 1	18
4	15
7	12
10	8
13	5
16	2
18	23
21	19
24	16
27	13
30	10

U Columbæ

d	h
May 1	15
4	10
7	5
10	0
12	19
15	15
18	10
21	5
24	0
26	19
29	15

RW Monoc.

d	h
May 1	3
3	1
4	23
6	21
8	18
10	16
12	14
14	12
16	10
18	7
20	5
22	3
24	1
25	22
27	20
29	18
31	16

RX Geminorum

d	h
May 6	23
19	4
31	9

RU Monoc.

d	h
May 1	6
2	3
3	1
3	22
4	20
5	17
6	15
7	12

RU Monoc.

h	d
May 8	10
9	7
10	5
11	2
12	0
12	21
13	19
14	16
15	14
16	12
17	9
18	7
19	4
20	2
20	23
21	21
22	18
23	16
24	13
25	11
26	8
27	6
28	3
29	1
29	22
30	20
31	17

RY Geminorum

h	d
May 6	20
16	4
25	11

Minima of Variable Stars of the Algol Type.—Continued.

R Canis Maj.

	d	h
May	1	13
	2	17
	3	20
	4	23
	6	2
	7	5
	8	9
	9	12
	10	15
	11	19
	12	22
	14	1
	15	4
	16	8
	17	11
	18	14
	19	17
	20	21
	22	0
	23	3
	24	6
	25	10
	26	13
	27	16
	28	19
	29	23
	31	2

Y Camelop.

May	1	13
	4	20
	8	3
	11	1
	14	18
	18	1
	21	9
	24	16
	27	23
	31	7

RR Puppis

May	2	16
	9	2
	15	12
	21	23
	28	9

V Puppis

May	2	1
	3	12
	4	23
	6	10
	7	21
	9	8
	10	19
	12	5
	13	16
	15	3
	16	14
	18	1
	19	12
	20	23
	22	10

V Puppis

	d	h
May	23	21
	25	8
	26	19
	28	5
	29	16
	31	3

X Carinæ

Period 13h

May	1	4
	2	6
	3	8
	4	10
	5	12
	6	14
	7	16
	8	18
	9	20
	10	22
	12	0
	13	2
	14	4
	15	6
	16	8
	17	10
	18	12
	19	14
	20	16
	21	18
	22	20
	23	22
	25	0
	26	2
	27	4
	28	6
	29	8
	30	10
	31	12

S Cancri

May	6	7
	15	18
	25	6

S Velorum

May	5	23
	11	21
	17	20
	23	18
	29	17

Y Leonis

May	1	19
	3	11
	5	4
	6	20
	8	13
	10	5
	11	22
	13	4
	15	7
	16	23
	18	15
	20	8

Y Leonis

	d	h
May	22	0
	23	17
	25	9
	27	2
	28	18
	30	11

RR Velorum

May	2	20
	4	17
	6	13
	8	10
	10	6
	12	3
	13	23
	15	20
	17	16
	19	13
	21	9
	23	6
	25	2
	26	23
	28	19
	30	16

SS Cancri

May	1	5
	4	12
	7	20
	11	3
	14	10
	17	17
	21	1
	24	8
	27	15
	30	22

RW Urs. Maj.

May	3	11
	10	19
	18	3
	25	11

Z Draconis

May	2	6
	3	15
	5	0
	7	17
	9	1
	10	10
	11	18
	13	3
	14	12
	15	20
	17	5
	18	13
	19	22
	21	6
	22	5
	24	0
	25	8
	26	17
	28	1

Z Draconis

	d	h
May	29	10
	31	18

SS Centauri

May	3	11
	5	22
	8	10
	10	21
	13	9
	15	20
	18	8
	20	19
	23	7
	25	18
	28	5

δ Libræ

May	1	1
	3	9
	5	17
	8	1
	10	9
	12	17
	15	0
	17	8
	19	16
	22	0
	24	8
	26	16
	29	0
	31	7

U Coronæ

May	2	5
	5	16
	9	3
	12	14
	16	1
	19	12
	22	22
	26	9
	29	20

115.1908 Ophi.

May	1	1
	3	11
	5	22
	8	9
	10	20
	13	6
	15	17
	18	4
	20	14
	23	1
	25	12
	27	22
	30	9

116.1908 Ophi.

May	1	5
	3	7
	5	8
	7	10
	9	11
	11	13

116.1908 Ophi.

	d	h
May	13	14
	15	16
	17	17
	19	19
	21	20
	23	22
	26	0
	28	1
	30	3

R Aræ

May	1	5
	5	15
	10	1
	14	12
	18	22
	23	8
	27	18

U Ophiuchi

May	1	12
	2	8
	3	4
	4	0
	4	20
	5	17
	6	13
	7	9
	8	5
	9	1
	9	21
	10	17
	11	14
	12	10
	13	6
	14	2
	14	22
	15	18
	16	14
	17	10
	18	7
	19	3
	19	23
	20	19
	21	15
	22	11
	23	7
	24	3
	25	0
	25	20
	26	16
	27	12
	28	8
	29	4
	30	0
	30	20
	31	17

Z Herculis

May	1	16
	3	13
	5	16
	7	13

Minima of Variable Stars of the Algol Type.—Continued.

Z Herculis			RZ Draconis			RR Draconis			RX Draconis			UW Cygni		
	d	h		d	h		d	h		h	d		d	h
May	9	16	May	27	9	May	1	2	May	26	5	May	13	22
	11	13		28	12		3	22		28	2		17	9
	13	15		29	14		6	17		29	23		20	20
	15	12		30	17		9	13		31	21		24	7
	17	15		31	19		12	9	RV Lyræ				27	18
	19	12					15	5	May	2	10		31	4
	21	15					18	1		6	1	W Delphini		
	23	12	RX Herculis				20	21		9	15	May	1	15
	25	15	May	1	17		23	17		13	5		6	11
	27	12		2	14		26	13		16	20		11	6
	29	15		3	12		29	9		20	10		16	1
	31	12		4	9					24	1		20	21
RS Sagittarii				5	6	U Scuti				27	15		25	16
May	2	5		6	4	May	1	17		31	5		30	11
	4	15		7	1		2	15	U Sagittae			RR Delphini		
	7	1		7	22		3	14	May	1	14	May	4	18
	9	11		8	20		4	13		4	23		9	9
	11	21		9	17		5	12		8	8		13	23
	14	7		10	14		6	11		11	17		18	13
	16	17		11	12		7	10		15	2		23	4
	19	3		12	9		8	9		18	11		27	18
	21	13		13	6		9	8		21	20			
	23	23		14	4		10	7		25	5	VV Cygni		
	26	9		15	2		11	6		28	15	May	1	14
	28	19		15	22		12	5	SY Cygni				3	1
	31	5		16	20		13	4	May	1	17		4	13
V Serpentis				17	17		14	3		7	17		6	0
May	2	4		18	15		15	1		13	17		7	12
	5	15		19	12		16	0		19	17		8	23
	9	2		20	9		16	23		25	17		10	11
	12	13		21	7		17	22		31	17		11	22
	16	0		22	4		18	21	WW Cygni				13	10
	19	10		23	1		19	20	May	4	4		14	21
	22	21		23	23		20	19		7	11		16	8
	26	8		24	20		21	18		10	19		17	20
	29	19		25	17		22	17		14	2		19	7
RZ Draconis				26	15		23	16		17	10		20	19
May	2	1		27	12		24	15		20	18		22	6
	3	4		28	9		25	14		24	1		23	18
	4	6		29	7		26	12		27	9		25	5
	5	9		30	4		27	11		30	17		26	17
	6	11		31	1		28	10	SW Cygni				28	4
	7	13		31	23		29	9	May	4	16		29	16
	8	16					30	8		9	6		31	3
	9	18	SX Sagittarii				31	7		13	19	UZ Cygni		
	10	21	May	1	3	RX Draconis				18	9	May	8	20
	11	23		3	5	May	1	14		22	23			
	13	2		5	7		3	11		27	13	143.1907 Andr.		
	14	4		7	9		5	8	VW Cygni			May	2	7
	15	7		9	10		7	6	May	3	23		5	1
	16	9		11	12		9	3		12	9		7	20
	17	11		13	14		11	1		20	20		10	14
	18	14		15	16		12	22		29	6		13	8
	19	16		17	18		14	20	UW Cygni				16	3
	20	19		19	20		16	17	May	3	11		18	21
	21	21		21	21		18	15		7	1		21	15
	23	0		23	23		20	12		10	11		24	10
	24	2		26	1		22	10					27	4
	25	5		28	3		24	7					29	22
	26	7		30	5									

Maxima of Variable Stars of Short Period not of the Algol Type.

Unless otherwise indicated the times of maxima only are given; and the times of minima may be found by subtracting the interval printed in parentheses under the names of the stars.

SY Cassiop.

	d	h
May	1	12
	5	14
	9	15
	13	17
	17	19
	21	20
	25	22
	30	0

RW Cassiop.

(−5 19)

May	11	22
	26	17

RX Aurigæ

(−4 0)

May	4	19
	16	10
	28	1

Y Aurigæ

(−0 18)

May	3	16
	7	12
	11	9
	15	6
	19	2
	22	23
	26	20
	30	16

T Monoc.

(−9 23)

May	12	15

W Geminorum

(−2 2)

May	8	12
	16	10
	24	8

ζ Geminorum

(−5 0)

May	1	14
	11	18
	21	21

RU Camelop.

(−9 12)

May	17	0

V Carinæ

(−2 4)

May	7	14
	14	7
	20	23
	27	16

T Velorum

(−1 10)

May	5	14

T Velorum

	d	h
May	10	6
	14	21
	19	12
	24	4
	28	19

W Carinæ

(−1 0)

May	3	23
	8	8
	12	16
	17	1
	21	10
	25	19
	30	4

S Muscæ

(−3 11)

May	1	11
	11	2
	20	18
	30	10

T Crucis

(−2 2)

May	1	2
	7	19
	14	13
	21	7
	28	0

R Crucis

(−1 10)

May	2	2
	7	22
	13	18
	19	14
	25	10
	31	5

S Crucis

(−1 12)

May	4	19
	9	11
	14	4
	18	20
	23	13
	28	5

RZ Centauri

May	1	16
	2	14
	3	13
	4	11
	5	10
	6	8
	7	7
	8	5
	9	4
	10	2

RZ Centauri

	d	h
May	11	1
	11	23
	12	22
	13	20
	14	19
	15	17
	16	16
	17	14
	18	13
	19	11
	20	10
	21	9
	22	7
	23	6
	24	4
	25	3
	26	1
	27	0
	27	22
	28	21
	29	19
	30	18
	31	16

W Virginis

(−8 5)

May	15	6

V Centauri

(−1 11)

May	4	18
	10	6
	15	18
	21	6
	26	18

R Triang. Austr.

(−1 0)

May	1	0
	4	9
	7	19
	11	4
	14	13
	17	23
	21	8
	24	17
	28	3
	31	12

S Triang. Austr.

(−2 2)

May	4	13
	10	21
	17	5
	23	13
	29	20

S Normæ

(−4 10)

May	6	2
	15	20
	25	14

RV Cassiop

(−1 10)

May	6	0
	12	1
	18	3
	24	4
	30	6

RV Ophiuchi Minimum.

May	2	22
	6	14
	10	7
	13	23
	17	16
	21	8
	25	1
	28	17

X Sagittarii

(−2 22)

May	7	16
	14	17
	21	17
	28	17

Y Ophiuchi

(−6 5)

May	8	22
	26	1

W Sagittarii

(−3 0)

May	6	14
	14	4
	21	18
	29	8

Y Sagittarii

(−2 2)

May	4	1
	9	20
	15	15
	21	9
	27	4

U Sagittarii

(−2 23)

May	1	21
	8	15
	15	9
	22	3
	28	21

β Lyræ

	d	h
	(−3	7)
	(−3	2)
May	2	7
	8	23
	15	5
	21	21
	28	3

κ Pavonis

(−4 7)

May	2	16
	11	18
	20	21
	29	23

U Aquilæ

(−2 4)

May	3	9
	10	10
	17	10
	24	11
	31	11

U Vulpeculæ

(−2 3)

May	2	17
	10	16
	18	16
	26	15

SU Cygni

(−1 7)

May	2	4
	6	0
	9	20
	13	17
	17	13
	21	9
	25	5
	29	2

η Aquilæ

(−2 6)

May	2	18
	9	22
	17	3
	24	7
	31	11

S Sagittæ

(−3 10)

May	4	7
	12	16
	21	1
	29	11

Maxima of Variable Stars of Short Period not of the Algol Type.

Continued.

X Vulpeculæ		T Vulpeculae		VZ Cygni		δ Cephei		SW Cassiop.	
d	h	h	d	h	d	d	h	h	d
(−2	1)	May 18	13	May 19	8	May 25	18	May 2	11
May 3	22	23	20	24	1	31	3	8	0
10	5	27	10	29	1	V Lacertae		13	13
16	13	31	21			(−1	16)	19	2
22	21	TX Cygni		Y Lacertae		May 3	15	24	15
29	4	May 14	22	(−1	10)	8	15	30	4
V Vulpeculae		29	15	May 4	9	13	14		
Minimum		UY Cygni		8	17	18	14	RS Cassiop.	
May 25	2	(−2	14)	13	1	23	13	(−1	19)
X Cygni		May 3	2	17	8	28	13	May 1	3
(−6	19)	10	22	21	16	X Lacertae		7	11
May 5	19	18	19	25	23	Minimum		13	18
22	5	26	16	30	7	May 3	11	20	1
T Vulpeculae		VZ Cygni		δ Cephei		8	21	26	8
(−1	10)	(−2	12)	May 4	7	14	8	RY Cassiop.	
May 5	6	(−3	6)	9	16	19	18	(−7	10)
9	16	May 9	15	15	1	25	5	May 8	4
14	3	14	8	20	10	30	16	20	8

Approximate Magnitudes of Variable Stars on March 1, 1909.

[Communicated by the Director of Harvard College Observatory, Cambridge, Mass.]

Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.	Name.	R.A. 1900. h	m	Decl. 1900. °	′	Magn.
X Androm.	0	10.8	+46	27	13.6*d*	T Arietis	2	42.8	+17	6	9.1
T Androm.		17.2	+26	26	13.0*d*	W Persei		43.2	+56	34	9.0
T Cassiop.		17.8	+55	14	8.8*d*	U Arietis	3	5.5	+14	25	9.2*d*
R Androm.		18.8	+38	1	13.6*d*	X Ceti		14.3	− 1	26	8.8 *i*
S Ceti		19.0	− 9	53	10.7*d*	Y Persei		20.9	+43	50	10.0
Y Cephei		31.3	+79	48	12.6	R Persei		23 7	+35	20	13.1*d*
U Cassiop.		40.8	+47	43	11.0*d*	Nov. Per. 2		24.4	+43	34	12.5
RW Androm.		41.9	+32	8	14.3*d*	T Tauri	4	16.2	+19	18	9.8
V Androm.		44.6	+35	6	13.3*d*	R Tauri		22.8	+ 9	56	<13
RR Androm.		45.9	+33	50	13.0 *i*	W Tauri		22.2	+15	49	12.6*d*
RV Cassiop.		47.1	+46	53	13.7 *i*	S Tauri		23.7	+ 9	44	12.0 *i*
W Cassiop.		49.0	+58	1	9.8	T Camelop.		30.4	+65	57	8.4 *i*
RX Androm.		58.9	+40	46	11.0	RX Tauri		32.8	+ 8	9	13.0
U Androm.	1	9.8	+40	11	12.5 *i*	X Camelop.		32.6	+74	56	9.0 *i*
S Piscium		12.4	+ 8	24	9.7 *i*	V Tauri		46.2	+17	22	12.5*d*
S Cassiop.		12.3	+72	5	13.0*d*	R Orionis		53.6	+ 7	59	9 6
U Piscium		17.7	+12	21	12.0	R Leporis		55.0	−14	57	10 0*d*
R Piscium		25.5	+ 2	22	11.0 *i*	V Orionis	5	0.8	+ 3	58	12.0 *i*
RU Androm.		32.8	+38	10	10.4 *i*	T Leporis		0.6	−22	2	12.0*d*
Y Androm.		33.7	+38	50	9.4 *i*	R Aurigae		9.2	+53	28	8.6
X Cassiop.		49.8	+58	46	10.0	S Aurigae		20.5	+34	4	9.0
U Persei		53.0	+54	20	8.1	W Aurigae		20.1	+36	49	<14
S Arietis		59.3	+12	3	11.6 *i*	S Orionis		24.1	− 4	46	11.0*d*
R Arietis	2	10.4	+24	35	8.6*d*	T Orionis		30.9	− 5	32	10.0
W Androm.		11.2	+43	50	12.7*d*	S Camelop.		30.2	+68	45	10.0
Z Cephei		12.8	+81	13	14.0	RR Tauri		33.3	+26	19	11.0 *i*
o Ceti		14.3	− 3	26	6.8	U Aurigae		35.6	+31	59	12.8*d*
S Persei		15.7	+58	8	9.4*d*	— Tauri		43.2	+19	2	<13
R Ceti		20.9	− 0	38	8.0 *i*	Z Tauri		46.7	+15	46	<12
RR Persei		21.7	+50	49	9.0 *i*	U Orionis		49.9	+20	10	10.8 *i*
U Ceti		28.9	−13	35	12.5*d*	Z Aurigae		53.6	+53	18	9.5 *i*
RR Cephei		30.4	+80	42	14.0	X Aurigae	6	4.4	+50	15	9.5 *i*
R Trianguli		31.0	+33	50	10 8*d*	SS Aurigae		5.8	+47	46	<13.5

Approximate Magnitudes of Variable Stars on Mar. 1, 1909—Con.

Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.	Name.	R. A. 1900. h	m	Decl. 1900. °	′	Magn.
V Aurigae	6	16.5	+47	45	9.6*d*	Z Bootis	14	1.7	+13	59	9.3 *i*
V Monoc.		17.7	− 2	9	13.3*d*	Z Virginis		5.0	−12	50	10.6
R Monoc.		33.7	+ 8	49	11.5	U Urs. Min.		15.1	+67	15	9.3
X Gemin.		40.7	+30	23	10.8 *i*	S Bootis		19.5	+54	16	9.7*d*
W Monoc.		47.5	− 7	2	11.0	RS Virginis		22.3	+ 5	8	11.5
Y Monoc.		51.3	+11	22	12.0*d*	V Bootis		25.7	+39	18	9.6
X Monoc.		52.4	− 8	56	7.2	R Camelop.		25.1	+84	17	11.0*d*
R Lyncis		53.0	+55	28	10.5*d*	R Bootis		32.8	+27	10	7.8 *i*
RS Gemin.		55.2	+30	40	10.8	V Librae		34.8	−17	14	9.0
V Can. Min.	7	1.5	+ 9	2	13.5*d*	U Bootis		49.7	+18	6	11.5
R Gemin.		1.3	+22	52	12.5	RT Librae	15	0.8	−18	21	9.6
R Can. Min.		3.2	+10	11	8.2	T Librae		5.0	−19	38	<12
RR Monoc.		12.4	+ 1	17	13.4*d*	Y Librae		6.4	− 5	38	10.6
V Gemin.		17.6	+13	17	13.8*d*	S Librae		15.6	−20	2	8.7
S Can. Min.		27.3	+ 8	32	12.6*d*	S Serpentis		17.0	+14	40	<12
Z Puppis		28.3	−20	27	13.8	S Coronae		17.3	+31	44	6.5
U Can. Min.		35.9	+ 8	37	10.3*d*	RS Librae		18.5	−22	33	8.8
S Gemin.		37.0	+23	41	9.4 *i*	RU Librae		27.7	−14	59	<11.8
T Gemin.		43.3	+23	59	13.6*d*	R Coronae		44.4	+28	28	9.7*d*
U Puppis		56.1	−12	34	14.0	X Coronae		45.2	+36	35	9.0 *i*
R Cancri	8	11.0	+12	2	11.6*d*	R Serpentis		46.1	+15	26	<13
V Cancri		16.0	+17	36	12.6*d*	V Coronae		46.0	+39	52	9.4 *i*
RT Hydrae		24.7	− 5	59	8.1	Z Coronae		52.2	+29	32	<12.5
U Cancri		30.0	+19	14	9.6 *i*	R Herculis	16	1.7	+18	38	9.0 *i*
X Urs. Maj.		33.7	+50	30	13.0*d*	RR Herculis		1.5	+50	46	9.3
S Hydrae		48.4	+ 3	27	11.6*d*	U Serpentis		2.5	+10	12	10.4
T Hydrae		50.8	− 8	46	10.2*d*	RU Herculis		6.0	+25	20	<12.5
T Cancri		51.0	+20	14	8.8	W Coronae		11.8	+38	3	<12.5
S Pyxidis	9	0.7	−24	41	9.2 *i*	U Herculis		21.4	+19	7	12.6
W Cancri		4.0	+25	39	10.4*d*	SS Herculis		28.0	+ 7	3	11.0*d*
X Hydrae		30.7	−14	15	12.5*d*	W Herculis		31.7	+37	32	<12.2
Y Draconis		31.1	+78	18	8.4 *i*	R Draconis		32.4	+66	58	12.6*d*
R Leo. Min.		39.6	+34	58	9.3*d*	S Herculis		47.4	+15	7	12.3*d*
RR Hydrae		40.4	−23	34	9.8 *i*	RV Herculis		56.8	+31	22	<12
R Leonis		42.2	+11	54	8.8*d*	RT Herculis	17	6.8	+27	11	10.6
Y Hydrae		46.4	−22	33	7.0	Z Ophiuchi		14.5	+ 1	37	11.0*d*
V Leonis		54.5	+21	44	9.0 *i*	RS Herculis		17.5	+23	1	8.7 *i*
R Urs. Maj.	10	37.6	+69	18	12.8 *i*	RU Ophiuchi		28.5	+ 9	30	10.0
W Leonis		48.4	+14	15	<12.6	RT Ophiuchi		51.8	+11	8	10.6
S Leonis	11	5.7	+ 6	0	9.6 *i*	RY Herculis		55.4	+19	29	11.4
R Comae		59.1	+19	20	<12.8	V Draconis		56.3	+54	53	12.0*d*
RW Virginis	12	2.1	− 6	12	7.2	U Draconis	19	9.9	+67	7	9.6 *i*
T Virginis		9.5	− 5	29	<12.6	R Cygni		34.1	+49	58	13.3*d*
R Corvi		14.4	−18	42	12.6	Z Cygni		58.6	+49	46	13.6*d*
SS Virginis		20.1	+ 1	19	7.0	S Cygni	20	3.4	+57	42	12.0*d*
Y Virginis		28.7	− 3	52	12.8*d*	U Cygni		16.5	+47	35	9.0 *i*
T Urs. Maj.		31.8	+60	2	<12	X Cephei	21	3.6	+82	40	<13
R Virginis		33.4	+ 7	32	9.5 *i*	T Cephei		8.2	+68	5	9.0 *i*
RS Urs. Maj.		34.4	+59	2	<12	S Cephei		36.5	+78	10	10.8*d*
S Urs. Maj.		39.6	+61	38	9.2 *i*	S Lacertae	22	24.6	+39	48	9.1*d*
RU Virginis		42.2	+ 4	42	13.0*d*	R Lacertae		38.8	+41	51	12.5 *i*
U Virginis		46.0	+ 6	6	11.4*d*	R Pegasi	23	1.6	+10	0	12.0*d*
RT Virginis		57.6	+ 5	43	8.6	V Cassiop.		7.4	+59	8	10.1*d*
R Hydrae	13	24.2	−22	46	8.4 *i*	Z Cassiop.		39.7	+56	2	14.5
S Virginis		27.8	− 6	41	10.6*d*	RR Cassiop.		50.7	+53	8	11.0
R Can. Ven.		44.6	+40	2	11.0*d*	R Casssiop.		53.3	+50	50	9.8*d*
RR Virginis		59.6	− 8	0	12.4						

The letter *i* denotes that the light is increasing; the letter *d*, that the light is decreasing; the sign <, that the variable is fainter than the appended mag-

nitude. The above magnitudes have been compiled by Mr. Leon Campbell of the Harvard College Observatory from observations made at the Vassar, Whitin, Mt. Holyoke, and Harvard Observatories.

SY Andromedae.—In A. N. 4306 Mr. A. A. Nijland of Utrecht gives three minima of this Algol-type variable from which he derives the elements

Minimum = 2418320.01 Gr. m. t. + 34.^{d}912 E.

Duration of stationary minimum	21.^{h}6
Duration of the entire eclipse	38.4
Duration of the waning or brightening	8.4
Maximum brightness	10^{m}.7
Minimum brightness	12.2

The Variable Star, 154428, R Coronae—was found by Mr. Leon Campbell to be faint on January 1, 1909, magn. 8.2. This star is usually of the magnitude 6.0, but occasionally undergoes marked and apparently irregular diminutions in light, sometimes becoming as faint as magnitude 13. The last diminution in brightness lasted from February 8 to September 6, 1905. On Nov. 12, 1908, its magnitude was 6.1, and on December 13, 1908, it was 6.9. Only two other stars of this class have been as yet discovered, *191033*, RY Sagittarii, and *054319*, — Tauri, the latter being now exceedingly faint. All three of these stars are followed here closely, both photographically and visually.

EDWARD C. PICKERING.

Harvard College Observatory, January 5, 1909.
No. 344, Astronomical Bulletin.

Elements of the Variable 69.1907 Persei.—In A. N. 4300 Mr. S. Enebo gives elements of this variable derived from about 150 observations after Sept. 11, 1907. The rise lasts about 1^{d}.2 and the range is from < 11^{m}.5 to 10^{m}.3

Maximum = 2417859.33 Gr. m. t. + 4^{d}.294 E.

Elements of the Variable 78.1907 Aurigae.—In A. N. 4300 Mr. S. Enebo gives as the probable elements of this star

Minimum = 2418046.37 Gr. m. t. + 0.^{d}666364 E.

Elements of the Variable 121.1907 Vulpeculae.—In A. N. 4300 Mr. S. Enebo gives elements of this star determined from observations of ten minima in 1907 and 1908. The star is of the Algol type, the normal magnitude being about 9.6, but waning to about 11.0 at minimum. The change of brightness extends over eight hours.

Minimum = 2417883.25 Gr. m. t. + 5^{d}.0505 E.

Elements of the Variable 52.1908 Geminorum.—In A. N. 4300 Mr. S. Enebo states that this variable is of the δ Cephei-type. From nine maxima and five minima, observed since Oct. 22, 1908, he derives the elements

Maximum = 2418263.37 Gr. m. t. + 5^{d}.57 E.

The range of magnitude is 9^{m}.8 — 11^{m}.4 and the ascent of the light curve occupies about one day.

New Variable Star, 1,1909, Ursae Majoris.—This is announced in A. N. 4303 by Messrs. Müller and Kempf of Potsdam. It is B D + 62° 1224 and the position for 1900 0 is

$$\alpha = 12^h\ 15^m\ 40.^s03;\ \delta = +\ 61°\ 51'\ 53.''9$$

From a long series of photometric measures taken during the years 1906-8 the period seems to be about 315 days. The minima are shorter than the maxima and are fairly represented by the elements

Minimum = 1906 Feb. 23 (2417265) + 315^d E.

The range of brightness is between 7.2 and 8.2 magnitude.

New Variable Star 2.1909 Andromedae.—In A. N. 4303 Prof. W. Ceraski announces a variable star 3′ west from the star BD + 25° 68. Its position for 1900.0 is given by H. H. Turner in A. N. 4307

$$\alpha = 0^h\ 27^m\ 07.^s27,\ \delta = +\ 25°\ 28'\ 38.''3$$

It was discovered by Mme. L. Ceraski being found upon five photographs with the following dates:

1907	Nov.	25	9½ mag.	1908	Nov.	17	11½ mag.
1908	Sep.	25	9½ mag.		Dec.	16	12 mag.
	Oct.	20	11 mag.				

New Variable Star 3.1909 Cephei.—In A. N. 4306 Prof. W. Ceraski calls attention to the star B D + 72° 1031, which is found by Mme. L. Ceraski from an examination of 28 plates taken in 1906-8 to vary between the magnitudes 9.5 and 10.5. The dates of the photographs are very scattered so that the period and type of variation are very uncertain.

GENERAL NOTES.

Astronomical No. 2. There has come to hand a neatly printed pamphlet of 18 pages by W. H. Bauser, Paris, Ill., 1909 which pretends to know more about astronomy than the whole generation of scholars in that science from Adam down to the present time. The boldness of its nonsense is so glaring that it needs a scientific pugilist to get any light through it.

The author ought to know that busy prominent scholars in science can not spend their time in explaining and elementally proving to him that his puerile theories are all wrong. If he wants to know the truths of science, why does he not go to some good school and study awhile and pay the bills? If he should he would probably get some of the help he really needs.

Regulation of the Light Ray in Photographic Objectives is the title of a lecture printed in the *British Journal of Photography* for February. In this lecture three things are discussed: (1) The purely geometrical theory of reproduction, (2) The theory of aberration, and (3) The doctrine of the regulation of the rays.

The lecture is fully illustrated by diagrams, so as to help the popular reader to understand clearly the points the lecturer is making. This lecture was by Dr. E. Wandersler. It is an instructive one.

Orbits of Asteroids. In a recent letter, Mr. Metcalf writers: "I now have about fifteen new asteroids which have been followed sufficiently long to assure good orbits. It was supposed that these orbits were being computed at the Naval Observatory in Washington. But a recent letter from the Acting Superintendent shows that such is not their intention. I must therefore appeal to the Astronomers of America to do this work, for the advancement of the Asteroid problem. I should be much pleased to hear from anyone who would be willing to make a contribution towards this work, by taking one or more of these planets."

The method employed by Mr. Metcalf, of giving a motion to the photographic plate equal to that of the asteroid, has proved extremely fruitful. Nearly all of the asteroids, discovered in America in recent years, have been found by him. The discovery of the asteroid, Eros, of the group whose mean distance is approximately that of Jupiter, and of the variations in light of several asteroids, has given a value to this department of astronomical research which it did not have previously. For two or three years, much useful work was done by the Naval Observatory in following the asteroids found by Mr. Metcalf, and it is hoped that its abandoment by the Naval Observatory is only temporary. It is eminently fitting that such work should be carried on by the government, as is done in Germany, since it cannot be maintained at private observatories. Meanwhile, some of the asteroids mentioned above will soon come to opposition. Unless ephemerides for them are computed, they cannot be found, and there is danger that they will be permanently lost. Therefore, it is greatly to be desired that, as requested by Mr. Metcalf, volunteers may be found at once, who will undertake the necessary computations.

Harvard Circular, No. 148. EDWARD C. PICKERING.
February 1, 1909.

Morehouse's Comet 1908 *c*. An admirable series of photographs of Morehouse's Comet, 1908 *c*, has been obtained by the Rev. Joel H. Metcalf at his Observatory in Taunton, Mass. The instruments employed were two doublets constructed by him. The first of these has an aperture of 12 inches, and a focal length of 87 5 inches. The second doublet has an aperture of 5.8 inches, and a focal length of 20 inches. The method which he has used so successfully, in discovering and following asteroids, was employed after September 15. The cross wires of a finding telescope were kept upon the image of a star, while the plate was moved every minute, by an amount, and in a direction, equal to the theoretical motion of the Comet, as determined from its ephemeris. This method proved particularly advantageous, since this Comet had no well defined nucleus which could be used for following in the ordinary way. The effectiveness of the method is shown by the smoothness of the trails of the stars. In all cases, two photographs were obtained simultaneously, with these telescopes, except on November 12, when the smaller instrument only was used.

A list of the photographs obtained is given in Table I. The number designating the plate is given in the first column. The numbers of the month and day are given in the second column, and the hour and minute in Greenwich Mean Time, in the third column. The Julian Day and decimal are given in the fourth, and the exposure, expressed in minutes, in the fifth column. The last two columns give the approximate right ascension and declination of the center of the plate. The exposure of Plate 650 was interrupted for 20^m, and that of Plate 671, for 5^m, by clouds. The nights of October 15, 16, and 17 were hazy, and the night of November 23 was very hazy.

TABLE I.

LIST OF PHOTOGRAPHS.

Plate.	Date. 1908.		Time.		J. D.	Ex.	R. A.		Decl.	
	m	d	h	m		m	h	m	°	′
616	9	3	15	23	8188.641	30	3	24.0	+67	0
621	9	14	13	17	8199.553	60	2	6.0	73	45
623	9	15	12	59	8200.541	60	2	0.0	74	30
625	9	19	12	49	8204.534	60	1	7.0	76	0
626	9	19	15	2	8204.626	137	1	7.0	76	0
627	9	20	13	10	8205.549	120	0	37.0	76	0
630	10	21	13	11	8206.549	120	0	26.0	76	45
635	10	29	12	47	8214.533	90	21	56.0	73	5
637	10	30	12	34	8215.524	89	21	45.0	72	0
645	10	12	12	10	8227.507	60	19	36.0	55	30
646	10	13	11	27	8228.477	30	19	33.0	53	10
647	10	13	12	16	8228.511	60	19	33.0	53	10
648	10	13	13	14	8228.551	16	19	24.0	52	10
649	10	13	14	2	8228.585	30	19	34.0	53	50
650	10	14	11	56	8229.497	60	19	32.0	50	50
651	10	14	13	45	8229.573	120	19	32.0	50	50
652	10	15	11	31	8230.480	30	19	30.0	50	10
653	10	15	12	22	8230.515	60	19	30.0	50	10
654	10	15	13	45	8230.573	90	19	30.0	50	10
655	10	15	15	38	8230.651	90	19	30.0	50	10
656	10	16	11	56	8231.497	78	19	27.0	48	0
657	10	17	12	52	8232.536	156	19	22.0	47	0
658	10	18	12	38	8233.526	120	19	12.0	53	0
660	10	19	13	42	8234.571	90	19	18.0	43	10
663	10	21	11	58	8236.499	90	19	14.0	39	30
667	10	22	11	46	8237.490	60	19	9.0	38	10
671	10	23	11	41	8238.487	62	19	14.0	36	45
675	10	24	12	9	8239.506	60	19	10.0	34	30
677	10	27	12	34	8242.524	60	19	3.0	29	30
678	10	27	14	5	8242.587	42	19	4.0	29	55
680	10	39	11	19	8245.472	50	19	4.0	25	0
681	10	30	14	30	8245.604	60	19	4.0	25	10
684	10	31	11	15	8245.466	50	19	2.0	23	45
685	10	31	12	44	8246.531	59	19	2.0	23	45
686	11	1	11	22	8247.474	60	19	1.0	22	30
687	11	1	12	56	8247.539	113	19	1.0	22	30
688	11	2	11	49	8248.492	30	18	57.5	20	45
689	11	2	12	21	8248.515	30	18	57.5	20	45
690	11	12	11	40	8258.486	120	18	57.0	9	0
691	11	13	11	2	8259.460	50	18	56.0	8	30
692	11	13	12	14	8259.510	84	18	56.0	8	30
694	11	15	11	6	8251.462	60	19	0.0	6	15
695	11	15	12	8	8261.506	61	19	0.0	6	15
697	11	16	11	5	8262.462	60	18	53.0	4	50
698	11	16	11	53	8262.495	22	18	53.0	4	50
701	11	17	12	28	8263.478	60	18	53.0	4	5
703	11	20	11	9	8266.465	70	18	55.0	2	5
705	11	21	11	10	8267.465	76	18	58.0	1	30
707	11	22	11	0	8268.465	68	18	57.0	+ 0	10
710	11	23	10	54	8269.454	8	18	54.0	— 0	50
711	11	24	11	0	8270.458	60	18	54.0	1	0
713	11	27	10	54	8273.454	49	18	58.0	3	20
716	11	29	10	50	8275.451	44	18	57.0	— 3	0

Reproductions of Plates 694, 701, 703, and 705 are shown in the accompanying half-tone engravings. Following the example of the Lick Observatory,

in the case of Daniel's Comet, L. O. Bulletin 126, double contact prints have been used to increase the contrast. Much detail is thus shown in the tail, although much of that near the nucleus is lost.

Reproductions of Plates 685 and 698 will be found in *Popular Astronomy*, 17, 53. EDWARD C. PICKERING.

Harvard Circular, No. 148,
Feb. 1, 1909.

Independent Day Numbers for the year 1910, as used at the Royal Observatory, Cape of Good Hope, has been received. The tables are for correcting the star places for 1911.

Spectrum of Comet Morehouse. In the January number of the *Astrophysical Journal*, appeared an article on the Spectrum of Comet Morehouse by Professors E. B. Frost and J. A. Parkhurst, which has been looked for by some astronomers ever since this bright comet appeared; for this method of study of it is so important that the information to come from it is greatly discussed.

Naturally a considerable portion of this paper is given to the detailed explanation of the appartus used, the photographic plates employed and the images of the comet obtained. That part of the paper devoted to the results obtained is of more general interest to those looking for results secured. We give some of the more important conclusions reached by the authors of this paper:

1. The lack of a continuous spectrum on any plate, though it was carefully looked for on them all. That means that the reflected light of the comet by which it was seen must have been very small relatively to the intrinsic light from the radiations of carbon, cyanogen, and in the unidentified bands.

2. These authors speak of the brightness of the comet, as shown in the spectra, and conclude that they might have begun work earlier in this regard if they had chosen to do so. Other spectroscopists have called attention to this point in the study of other comets earlier.

3. The writers avoid the unsettled question of the precise origin of the "carbon" bands (often ascribed to ascetylene especially) by designating them "carbon."

"The presence of the third and fourth bands were seen beyond doubt. The absence of the fifth seems equally rare. The third cyanogen band is unquestionably present, and the fourth and first appear to be assured; but the second is certainly lacking."

4. The attempts to trace the separate streamers into the tail was difficult because of their interlacing. But on the best negatives, this could be done more than two degrees from the head; "*following the bends in the tail.*" The divergence of two sharp streamers for twenty degrees on each side of the main tail, showing a deviation between themselves of at least forty degrees, is certainly an important observation. The facts that these streamers so diverge and even pass into the bends of the tail will have an evident bearing on the theory of the constitution of the tails of comets.

5. The writers note that the spectrum of the Morehouse Comet, during their observations, has remained unchanged, apparently although, in physical appearance, it has shown extraordinary activity.

6. In this regard the Morehouse Comet is different from comet Daniel of last year. The authors emphasize the importance of securing early observations of faint comets, not only from the work they have done on this one, but also on account of like suggestions from others who have observed the spectra of other faint comets.

7. This work and other similar to it will furnish some interesting tests of the Bredichin theory of a different chemical composition of differently curved tails. It will be observed that the comparatively straight tail of the Morehouse Comet should have shown the spectrum of hydrogen, according to that theory, instead of that of "carbon" and cyanogen. Possibly other observers have determined "on Sept. 16, when the tail was violently curved at a large angle from its direction before and after that date," the manner in which the "carbon" and cyanogen radiations follow the convolutions in the tail of the comet. If so, such information would probably be helpful in this important study.

Publications of the Lick Observatory Vol. VIII. This volume is in the series of the University of California Publications, and, of course, done by the state printer. It is a fine piece of work. It is quarto in form, and has about thirty pages of descriptive matter followed by a list of photographs of nebulae and clusters covering about sixteen pages. The remainder of the volume contains sixty-eight plates of the nebulae and clusters given in the preceding list.

The photographic work from which these plates was made was done by James Edward Keeler, by the aid of the Crossley reflector.

In his hands, the old reflector seemed to have a new and a marvelous power, for he was convinced that the catalogue of 13,000 nebulae then known, by the power of that instrument could be increased, probably to a half million.

The two points of real discovery that Professor Keeler made with this great reflector were: (1) Many thousands of unrecorded nebulae exist in the sky. (2) Most of these nebulae have a spiral form.

The purpose of this volume is to reproduce and make available for study, the larger and more interesting nebulae and clusters. The difficulties attending a good reproduction of fine astronomical photographs are very great. The two principal ones are: (1) The tendency of the process to exaggerate the contrasts of shade, and (2) the certainty of losing much fine detail. The editors of this volume have taken great care to get the truest results they could by the best known processes available at the present time.

The Lick Observatory people are to be congratulated on the excellency of the work shown in this record-making volume. It is a worthy tribute to the memory of the scholarly astronomer James E. Keeler.

Suspected Causes of Earthquakes.— The frequency and the alarming results of earthquakes in recent years have called the attention of physicists to this class of natural phenomena more generally and more effectively than ever before.

The reasons for the present activity are:—the search for the causes of earthquakes, the number and violence of recent ones, and the great losses of life and property occasioned by them.

Professor H. H. Turner, F. R. S. of Oxford, England, has recently published a paper in the *London Times* on the frequency of earthquakes in the light of their suspected causes. That paper with other important ones on the same subject has drawn attention to this matter in a very unusual and effective way. Some

of the facts brought out are suggestive of the ways in which an attempted study has been going on especially for the last fifteen years.

During this period a series of earthquake observatories have been constructed, which were equipped with very delicate instruments by which observers could detect and record the tremors of the earth's crust very exactly in regard to time and extent. This record is reliable because it is automatic and continuous. From these records, it appears, that there are every thirty years some thirty thousand minor shocks of the earthquake in different localities. Of all these only sixty are "world-shaking" and observable at a great distance. The Italian earthquake, a little while ago, was one of this class.

Professor Turner speaks further on the distribution of earthquakes in time, of their increase or decrease in frequency, of the need of a catalogue of those which have produced marked structural damage, of the question of their periodicity and of their prediction, and briefly as to their causes. In regard to the causes of these earth tremors a very suggestive statement is made in *Current Literature* for February pp. 214 and 215, as follows: "A shifting of the Earth's axis, even to the slightest degree, would impose a great strain on some parts of the Earth's crust; and this might explain earthquakes, and in turn lead to appreciable results in foretelling them."

This rather new theory for the cause of earthquakes has started a discussion of general interest among scientists.

Annuaire Astronomique for 1909 is at hand. The forms of its tables and illustrative examples are helpful. Its colored map of the world divided into hours by colored, vertical bars is a useful device in locating places in standard time.

A Study of Overcast Skies. An article on the theme, "A study of overcast skies" by Edward L. Nichols in the February *Physical Review*, 1909, is a very suggestive one. It is illustrated by a series of curves, the data for which were obtained in the laboratory by the use of an instrument called a spectrophotometer.

The conclusion reached regarding some phases of this study are, that the "selectivity of ordinary sky-light is due on the one hand to light reflected from the surface of the ground to the atmosphere, and on the other to selective reflection which takes place in the upper layers of the atmosphere, and which is cut out by the intervention of a layer of mist or cloud, so that the light from overcast skies is more directly related to sunlight, although not as to the distribution of intensities, than is the light commonly observed in the case of unclouded skies."

Magnetic Tables and Magnetic Charts.—A volume of the United States magnetic tables and magnetic charts for 1905 by L. A. Bauer, inspector of magnetic work and chief of the division of terrestrial magnetism, printed in 1908 has reached us. The volume is largely statistical and it is interestingly full in this regard. The delightful feature is the case of charts that accompany it. They are the finest set of such charts we have seen.

Measurements of the Intensification of Aqueous Bands in the Spectrum of Mars.—Frank W. Very at Westwood Astrophysical Observa-

tory, Mass., has recently published an important paper, Bulletin No. 36 Lowell Observatory, Flagstaff, Arizona, giving a full set of measures on the intensification of aqueous bands in the spectrum of Mars. The concluding paragraph of that is as follows:

To understand the full significance of this determination of water vapor in the atmosphere of Mars, it must be remembered that Flagstaff is surrounded by deserts, and in winter not only the relative humidity, but also the absolute amount of moisture in the air, is small and much below the average moisture-content of the Earth's atmosphere. Moreover the elevation of the station brings it above nearly half of the total moisture in a vertical column of air from sea-level up. One and three-quarters times the aqueous absorbent mass over Flagstaff is therefore still only a fraction of the average water vapor present in the Earth's atmosphere. Considering how large a part of the Earth has a tropical, or both a tropical and an oceanic climate, and that this preponderance of moist regions is further enhanced when the Earth is viewed in projection by an observer at a distance in the plane of the equator, also that the data for temperature and moisture in the upper air are largely derived from balloon ascents made in pleasant weather when moisture is relatively deficient, the estimates of total atmospheric moisture derived from observations in high temperate latitudes, which give from twenty-five to thirty millimeters of precipitable water in summer, need to be nearly doubled to represent the average atmospheric moisture of the Earth in comparison with that of a planet also viewed equatorially. The mean path of the rays through the Earth's atmosphere on the five nights of observation was 1.43 times the vertical depth of the air-layer, which, for an aqueous vapor-content of one grain per cubic foot of surface air, is equivalent to a vertical column containing $1.0 \times 1.43 \times 2.29 = 3.27$ grams of water vapor per cubic meter at the surface, capable of giving a layer of water about eight millimeters deep if all of the vapor in the atmospheric column were to be condensed. The average layer of precipitable water on Mars may be taken as $1.75 \times 8 = 14$ mm., while the mean value for the Earth is probably three or four times as great.

Westwood Astrophysical Observatory,
Westwood, Massachusetts, January 5, 1909.

Science Year Book for 1909 is a neat companion of those of preceding years. This is the ninth year that we have used the book, and we know of nothing in the English language of its kind equal to it. It is a daily diary; it is a scientific directory in a host of things that a scientific man wants to know. It is a summary of late astronomical, physical and chemical tables, showing very well the progress and the present condition of science in these and other kindred lines of modern practical research. The four colored constellation charts, chart of equal magnetic variation, cut nearly to scale cloud and crust of Earth to show thickness and relative heights; cut showing increase of population of the five principal nations of the Earth in the last hundred years; interesting physical and chemical notes; silvering glass mirrors, fusible alloy; how to distinguish metals; shrinkage of castings; expansion of materials by heat; conductivity of metals, composition of alloys; explosives; size of molecules; energy of illuminants; specific gravities and weights; metrology; metric weights and measures; watts, kilowatts and horse-power; value of foreign moneys, etc: these topics give an illustration of the variety and the extent of the information to be obtained from the useful hand book.

Taking up the sciences of 1909, a general summary is given in one page. The progress in astronomy for the year is condensed to about one and one-fourth pages. Bacteriology, botany, geographical science, heredity, and physics are treated in the same way. A few pages are given to a glossary of recently introduced scientific terms and names. They are very helpful and instructive to most, if not all, pouplar readers. A page of scientific and technical periodicals, a directory of English universities; an extended table of scientific and learned societies; prizes and awards; medals and funds awarded in 1908 give information very difficult to get elsewhere. The biographical directory with titles covering about forty pages is a prominent and a very useful feature in the book. The full pages for a daily diary, the ruled pages for accounts and correspondence make the work complete in detail.

The book is heartily commended as one, not only of real scientific value because of its authority, but it has great value because it supplies so much information in ready reference for practical daily use.

Elementary Treatise on Theoretical Mechanics. This new book is by J. H. Jeans, M. A., F. R. S., a fellow of Trinity College, Cambridge, England, and now Professor of Applied Mathematics in Princeton University. It is published by Messrs. Ginn and Company, Boston and Chicago.

We have examined this new book carefully and somewhat thoroughly because it treats of a branch in mathematics that experienced teachers and practical mathematicians are interested in especially just now. The methods of experimental laboratory work on the one hand, and the graphical methods in mathematics on the other, have come to have such a prominent place in modern instruction that there is a danger of omitting, or turning aside from, a study of the more powerful and more subtile methods of mathematical analysis involving the calculus, in its elementary and in its higher branches. The former methods are limited and special in their applications, the latter are general and more rigorously exact in their grasp for either theoretical or practical study in the various fields of scientific investigation. It is to be regretted that the instruction in some, if not many, of the leading technical schools in which the applied mathematics is made prominent, should deal so largely in the former and weaker methods. It would be much better if the aim were, in all advanced instruction to ground the student more thoroughly by giving him a working knowledge of analytical methods so as to equip him to attack problems in a generalized way.

In our opinion, this is the one potent reason why our schools in the pure and the applied mathematics are turning out, in recent years, so few able mathematicians. It is now frequently remarked by the older scholars that one can almost count on his fingers, the young mathematicians who are showing any special promise in the broad field of severe, analytical investigation now open on every hand in science as never before in the history of the world.

We have said this much to introduce a book that in our judgment, starts the study of mechanics in the right way. Under the guidance of an experienced and apt teacher, the student will be led to grasp this subject, in a way to make it mean something to him, from the beginning, as well as to lead him on indefinitely in the right direction, and by developing a conscious strength in reasoning power that is every ready and even anxious to try new and hard original work.

To be more particular, we will show what we mean by these general statements. If one turns to page 26, he will get the author's ideas of the definitions of force, momentum, action and reaction. The essential character of these definitions and the illustrations accompanying strike right at the root of the subject, and give, in our judgment, a clear start in its study.

The themes of work and kinetic energy are presented in plain and definite way. The graphical illustration and the analytical development side by side, can not fail to interest and instruct any student who has the proper elemental training to read these methods and thoughtfully to grasp their meaning.

Then if the student is ambitious and the experienced instructor inclined, some fine work may be done in chapter 12 under the head of generalized co-ordinates. Both will find there something to do, that certainly will be worth their while.

An Astronomer's Wife.—To those interested in the quiet power back of the lives of so many great men, or in that back of the life of this particular great man, the late astronomer, Asaph Hall, or to any interested in a fascinating romance of an American woman whose early life dates back into the desperate struggles for life among the pioneers, we commend this little biography of Angeline Hall, written by Angelo Hall of Annapolis, Maryland, third son of Mr. and Mrs. Asaph Hall, and published late in 1908 by Nunn and Company, of Baltimore.

It is written in a simple conversational style and treats very familiarly of the early life of both parents, and especially of the varied experiences of the less-known mother who was herself quite a typical American woman; in school at the age of three, reading church history at twelve, intensely interested in the woman's suffrage and slavery questions during her college days, and quite on the road to becoming a reformer when the carpenter Asaph Hall came under her instruction in mathematics and science in McGrawville! She seems to have been the one who first recognized Asaph Hall's exceptional mathematical ability and later, after their marriage, the one who urged him to make the necessary preparation to devote himself entirely to his astronomical aspirations, although it meant for her the giving up entirely her own plans, her literary aspirations, and made her merge her life uncomplainingly with that of her husband, and with him face for years poverty, hard work, and much trouble, always greatly hampered by her own physical frailty.

This little volume of one hundred twenty-nine pages gives a graphic picture of the home and home-life of the great astronomer whom all honor for his brilliant discoveries, for his long and systematic observations especially of planets, their satellites and consequent investigations of their orbits, of double stars, and for his determinations of stellar parallax; and centrally, through the eyes of a loving son who sees the imperfections of that home of genius perhaps a little too clearly, is the master link in the family bond, the wife and mother, Angeline Stickney Hall.